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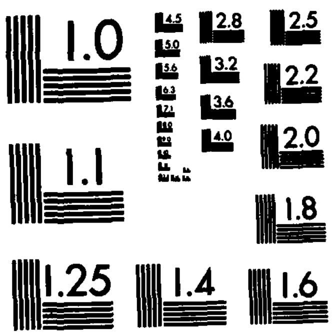

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VSC-TR-82-26

AUTOMATIC SEISMIC DISCRIMINATION SYSTEM (ASDIS)

W. E. Farrell

SEMIANNUAL TECHNICAL REPORT

S-CUBED
P.O. Box 1620
La Jolla, California 92038

November 1981

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report, modeled on MIL-STD-483(USAF), contains most of the material usually found in a Computer Program Development Specification. It gives detailed requirements for a computer program which is to perform automatic seismic discrimination. The proposed computer program, an expansion of one currently in use at the Seismic Data Analysis Center, is logically divided into two parts. The first part makes measurements on seismograms (feature selection). The measured features include time domain amplitudes, frequency domain amplitudes, narrowband filtered amplitudes, complexity and autoregressive moving average

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(ARMA) coefficients. The second ~~logical~~ part combines the features for each seismic station in an optimal manner, using the techniques of multivariate linear discriminant analysis. Statistical data analysis, ~~per se,~~ is not included within the proposed computer program. The results of the prior analysis of training data are made available to the program in the form of feature weighting factors.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. SCOPE

1.1 IDENTIFICATION

This report describes the requirements for performance and design of a computer program identified as the Automatic Seismic Discrimination System (ASDIS). It formalizes and extends the automatic discrimination system described by Farrell, et al. (1981). Although this report generally adheres to the guidelines spelled out in part 1 of the two part specification defined by MIL-STD-483 (USAF), it is not an official Computer Program Development Specification (CPDS).

1.2 FUNCTIONAL SUMMARY

1.2.1 Purpose of Specification

This report is used to define the discrimination techniques, the processing software, the operating parameters and procedures, and the data base requirements which will satisfy the needs for an automatic event discrimination system. This system is to exist in two forms. The first form will be a stand-alone computer program used for perfecting methods of automatic seismic discrimination. The second form will be a program module to be integrated into the Regional Event Location System (RELS) currently under development at the VELA Seismological Center. For this later application, ASDIS must be compatible with the program DISE (Discrimination and Identification of Seismic Events) described by von Seggern (1981).

1.2.2 ASDIS Functions

The ASDIS will be a computer program which performs a variety of sophisticated discrimination tasks automatically. It is designed to identify and evaluate seismic events. The ASDIS will require access to large volumes of seismic wave-form data and associated alphanumeric data. ASDIS output will consist of both softcopy CRT displays and hardcopy printer/plotter reports. The discrimination tasks to be performed by the ASDIS consist of the major processing functions summarized in the following two subparagraphs.

1.2.2.1 Feature Selection

Feature selection includes the automatic seismogram analysis functions such as seismic phase selection, signal amplitude and period measurement, signal-to-noise ratio (SNR) measurement, spectral measurements of signal shape, narrowband envelope calculations, complexity factor calculations, and spectral ratio measurements. It further covers the conversion of raw signal amplitude measurements into signal magnitudes using generally accepted formulas.

1.2.2.2 Linear Discriminant Analysis

Event identification is based on the value obtained when a linear combination of seismogram features is formed. This "dot product" uses archived sets of feature weights, and may perhaps be taken only over a subset selected from the complete range of features calculated for each wave-form comprising the event. The discriminant analysis is performed not only upon individual station features, but also upon a network average set of features.

1.3 EXCLUDED FUNCTIONS

Since ASDIS is to perform its operations automatically, there is very little operator intervention beyond the initial stage of setting up the program parameters. For automatic operation to be successful, a certain number of ancillary operations must be executed before data is passed to the ASDIS. These are described in the next five paragraphs.

1.3.1 Event Location

Although ASDIS can process a single isolated seismogram, it is anticipated that in the majority of applications, seismograms will have been associated to form an event. It is assumed that the event has been at least provisionally located and that the location and origin time are made available to ASDIS. Event location is required in order to convert signal amplitude measurements into magnitudes through the various distance factors. It is assumed, further, that as part of the event location procedure both a surface focus solution and a free depth solution have been obtained and that the RMS arrival time errors for each of these conditions are made available. As part of the event location procedure, it is further assumed that predicted phase arrival times, principally for the P-wave, the Love wave and the Rayleigh wave, have been evaluated and stored for access by ASDIS. (A subsequent version of ASDIS should have the capability of computing phase arrival times.)

1.3.2 Event File Creation

ASDIS assumes that all alphanumeric data pertaining to an event and the digital seismograms themselves have been collected together on a few high-speed random access files in a manner similar to that described by Farrell, et al. (1981, Section 2.1.1). We refer to the collection of digital seismograms as the event wave-form file. We refer to the associated alphanumeric parameter/identification list as the event header file. Each of these may, in fact, be several distinct physical files. All digital seismograms must be normalized so that a unit count is equivalent to 1.0 nm/s velocity at 1.0 Hz for short-period data or 0.04 Hz for long-period data. All horizontal component data shall have been rotated into an axis system pointing towards the source as seen from each station. (A subsequent version of ASDIS should have the capability of forming event files including retrieval, rotation and scaling of individual segmented wave-forms.)

1.3.3 Wave-form Preprocessing

ASDIS performs no checks on the validity of the data passed to it. It does not correct for random spikes or data drop-outs, nor does it ensure that the desired seismic phase is contained within the seismogram window. It is mandatory that these quality control operations be performed interactively by an analyst prior to the execution of the ASDIS program. A number of functional requirements for wave-form preprocessing were described by Sutton and Brady in the Discrimination/Final Evaluation Subsystem Report (Sutton and Brady, 1980); and some of these may be incorporated into a subsequent revision of ASDIS.

1.3.4 Surface Wave Path Corrections

The character of surface wave seismograms depends critically upon the propagation path. It is generally thought that the efficacy of surface wave discrimination can be improved by removing path dependent effects. The best studied method for path corrections is the method of matched filtering, which may be performed either by correlating an observed seismogram against a theoretical seismogram, or else by correlating an observed seismogram against a reference seismogram recorded previously along a similar path. ASDIS can perform neither of these functions itself, but it can process correlated long-period seismograms just as easily as it can process the original recordings.

1.3.5 Statistical Analysis of Training Data

Being an automatic system, ASDIS inevitably lags many months behind the current state-of-the-art in discrimination methodology. This is primarily reflected in the requirement that ASDIS contain in its data base the set of linear discriminant weights inferred from the prior analysis of a large set of training data. The training data most exhaustively studied up to the present has been the data assembled by the VELA Seismological Center for the Area of Interest (AI) experiment. Methods of performing discrimination based upon statistical combinations of seismogram features were discribed by Rivers, et al. (1979a; 1979b; 1979c) and Farrell, et al. (1981). It is assumed that calculations similar to those have been performed upon a training set, and that the linear discriminant weights are made available to the ASDIS program.

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3. REQUIREMENTS

The ASDIS shall be designed in accordance with all requirements defined in this chapter. These base line requirements have been established by the following methods:

(a) By a series of S^3/GEOTECH/VSC meetings and conferences during which the basic requirements for automatic discrimination have been defined.

(b) By evaluation of the hardware currently installed or under procurement for the Regional Event Location System (RELS) at the Seismic Data Analysis Center (SDAC).

(c) By evaluation of applicable literature in the area of seismic discrimination, principally the several reports published at the conclusion of the VSC Area of Interest experiment.

(d) By evaluation of a rudimentary automatic discrimination system (Farrell, et al., 1981) implemented on the PDP 11/70 computer system at the Seismic Data Analysis Center.

3.1 COMPUTER PROGRAM DEFINITION

The Automatic Seismic Discrimination System (ASDIS) shall be a modular software system designed to discriminate between earthquake seismograms and explosion seismograms. The ASDIS shall be based on the discriminants and statistical procedures defined herein, and shall be developed for use with minimal operator intervention. The system shall allow routine automatic application of an established set of signal measurement procedures and statistical procedures by a moderately trained operator/analyst.

3.1.1 System Capacities

The computer memory and storage areas required by the ASDIS program include:

(a) Computer memory areas for program load module (PLM) execution.

(b) Direct access space (high-speed disc) for storing both the program load module and data.

(c) Backup storage space for ASDIS program source code modules.

Any memory required by the host computer system (HOS), for instance that required by a system supervisor program, shall be considered as an additional capacity requirement for the ASDIS.

3.1.1.1 Program Execution Area

The host system memory area must have sufficient capacity to execute the ASDIS program. The amount of memory required will depend upon the ASDIS program size and the program execution procedures incorporated. The rudimentary automatic discrimination system currently operational at the SDAC PDP 11/70 computer contains approximately 2000 lines of higher order language (HOL). Using the rule of thumb that one line of FORTRAN translates into approximately five lines of assembly language code, the estimated size of the current system is appoximately 20,000 bytes. The additional code necessary to implement the full range of requirements specified herein is estimated to be approximately 50 percent larger for a total of approximately 30,000 bytes. Thus, the ASDIS can be contained within a single load module and no overlays will be required.

3.1.1.2 Load Module Storage

The ASDIS program load module shall be retained on a direct access storage device to allow immediate access for execution. The storage capacity requirements for this device will be on the order of 30,000 kilobytes.

3.1.1.3 Data File Storage

Direct access storage shall be provided for the various on-line data sets required by the ASDIS. These data base requirements are defined in Section 3.5.

3.1.1.4 Program Source Code

A backup copy of all ASDIS source code shall be maintained on magnetic tape, or an equivalent device. The storage capacity required by this device will be dependent upon ASDIS program size, but will be on the order of 50 kilobytes.

3.1.1.5 Reserve Area

An area of contiguous unused memory shall be reserved in the host computer for future expansion of the ASDIS program. The minimum reserved capacity shall be equal to 50 percent of the program execution area defined in Section 3.1.1.1.

3.1.1.6 System Timing

The system response time will be directly dependent upon the execution speed of the host computer system. Programming and input/output techniques shall be incorporated which reduce to the maximum extent possible the response time of the ASDIS. Since the ASDIS is not interactive, it is not necessary to service operator requests in real time. It is possible to estimate the ASDIS execution time as follows. If we let:

T_f = time for a 1024 Point Fast Fourier Transform (FFT)

N = number of seismograms comprising the event

α = data input/output time and non-FFT operations expressed as a fraction of the single FFT execution time T_f

T_t = total execution time

then

$$T_t = N\,(10\,T_f)(1 + \alpha) \quad .$$

3.1.2 Interface Requirements

The ASDIS shall be designed to be compatible with all interfaces defined in the remaining subparagraphs of this section.

3.1.2.1 Interface Block Diagram and Summary

The minimum essential functional interfaces of the ASDIS are presented in block diagram form in Figure 3.1.2.1. The blocks and interconnections in this diagram are intended to show functional relationships between the various devices. They do not necessarily reflect actual hardware interface design. The ASDIS will consist of a software computer program which will be executed by a host computer central processing unit (CPU) and its associated system supervisor or control program. This CPU will interact with an ASDIS operator to provide operational control of the ASDIS. Wave-form and alphanumeric data files that will be used by the ASDIS will reside on peripheral storage devices within the host computer system.

Primary ASDIS operational messages consist of data exchange between the ASDIS operator and the host computer system. These data include:

(a) Operator entered requests and parameters.

(b) Printer/plotter reports.

(c) Processing results.

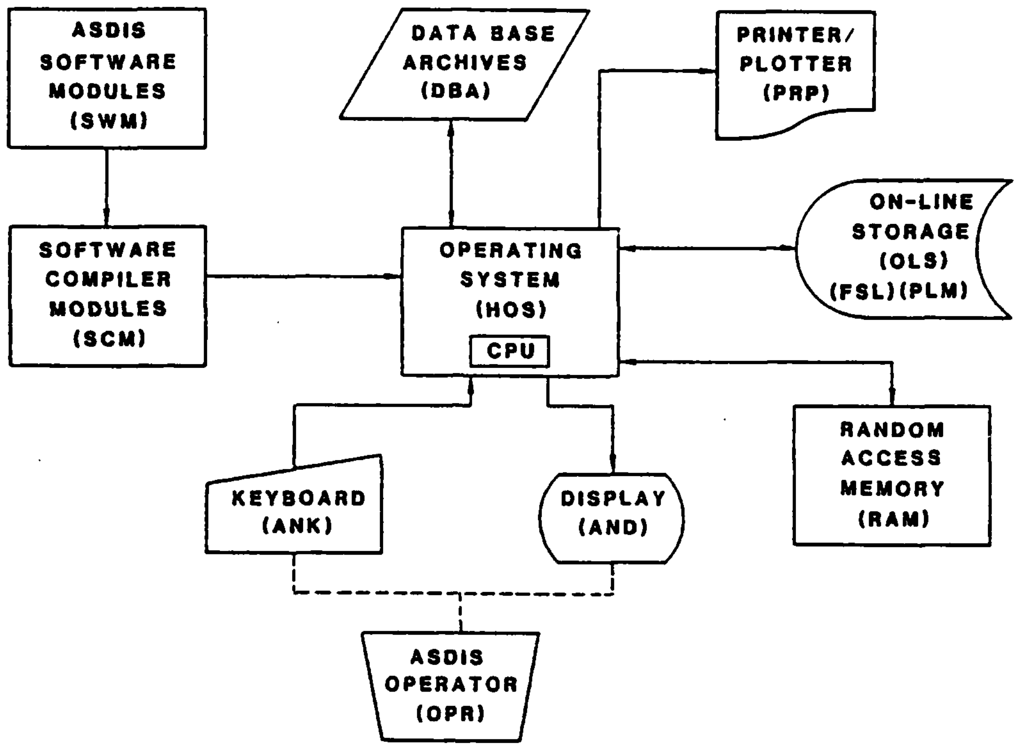
3.1.2.2 Detailed Interface Definition

3.1.2.2.1 ASDIS Operator (OPR)

The ASDIS operator will control all ASDIS functions from the alphanumeric keyboard (ANK). The operator will use this keyboard to enter requests and parameters into the ASDIS.

3.1.2.2.2 Alphanumeric Keyboard (ANK)

The Alphanumeric Keyboard (ANK) consists of an electronic keyboard which is conveniently positioned. The ANK shall contain



Abbreviations	Title	Reference
AND	ALPHANUMERIC DISPLAY	3.1.2.2.3
ANK	ALPHANUMERIC KEYBOARD	3.1.2.2.3
CPU	CENTRAL PROCESSING UNIT	3.1.2.2.5
DBA	DATA BASE ARCHIVES	3.1.2.2.12
FSL	FUNCTION AND SUBPROGRAM LIBRARY	3.1.2.2.10
HOS	HOST COMPUTER OPERATING SYSTEM	3.1.2.2.8
OLS	ON-LINE STORAGE	3.1.2.2.7
OPR	ASDIS OPERATOR	3.1.2.2.1
PLM	ASDIS PROGRAM LOAD MODULE	3.1.2.2.11
PRP	PRINTER/PLOTTER	3.1.2.2.4
RAM	RANDOM ACCESS MEMORY	3.1.2.2.6
SCM	SOFTWARE COMPILER MODULES	3.1.2.2.9
SWM	ASDIS SOFTWARE MODULES	3.1.2.2.9

Figure 3.1.2.1 ASDIS Interface Block Diagram.

alphabetic, numeric and special character keys. It would be convenient if the ANK had a limiting editing capability so that each line could be corrected before being submitted to the host. The ANK will be used by the ASDIS operator to enter commands and parameters.

3.1.2.2.3 Alphanumeric Display (AND)

The Alphanumeric Display (AND) shall be a video terminal upon which text entered on the ANK is displayed and to which the host system transmits messages and commands to the operator.

3.1.2.2.4 Printer/Plotter (PRP)

The Printer/Plotter (PRP) device provides hardcopy output of the alphanumeric display, processing results, and special reports. The PRP shall be a dot matrix or dry process electrostatic device located adjacent to the alphanumeric keyboard. It shall comply with the following special requirements:

(a) The PRP shall be capable of providing page reports that vary in size from 8 1/2 inches by 11 inches to 11 inches by 30 inches.

(b) The plotting resolution shall be at least 200 points per inch.

3.1.2.2.5 Central Processing Unit (CPU)

The Central Processing Unit (CPU) is the device which fetches and executes the ASDIS program instructions. The CPU shall comply with the following specifications.

(a) Standard arithmetic operations shall be provided including multiply/divide.

(b) Floating point data processing shall be provided with an accuracy of at least six decimal places for single precision, and at least 12 decimal places for double precision processing.

(c) The CPU shall be capable of processing 16 bit and 32 bit integer data both internally and as input/output.

(d) The CPU interface shall support the ASDIS response time requirements defined in Section 3.1.1.6.

3.1.2.2.6 Random Access Memory (RAM)

Random Access Memory (RAM) provides the computer memory area required for execution of the ASDIS program and it provides, also, storage areas for internal tables and parameters used by the ASDIS. Word sizes, capacity and access times for this memory shall be compatible with the ASDIS processing requirements defined in Section 3.2 and the subparagraphs therein.

3.1.2.2.7 On-line Storage (OLS)

On-line direct access device storage shall be provided for the various data sets required by the ASDIS. On-line storage shall include, but is not limited to, the following:

(a) The ASDIS program mode module (PLM) (see Section 3.1.2.2.13).

(b) ASDIS tables and special files (see Section 3.5).

3.1.2.2.8 Host Computer Operating System (HOS)

The Host Computer Operating System (HOS) consists of a system supervisor or control program that, together with the host system CPU, controls execution of the ASDIS program. The HOS used will be dependent upon the hardware configuration of the host computer system.

3.1.2.2.9 Software Compiler (SCM)

Software Compiler Modules (SCM's) consist of host system programs used to convert the ASDIS program source code statements into the object code format required by the host computer for execution. Compilers capable of compiling the programming languages defined in Section 3.3.1.9 and subparagraphs therein shall be incorporated within the host system.

3.1.2.2.10 Function and Subprogram Library (FSL)

The Function and Subprogram Library (FSL) consists of mathematical subprograms and service subprograms supplied with the host computer system to support the programming language used. These subprograms consist of often used functions such as square root, log functions, sine, cosine, et cetera. The actual functions required shall be determined during ASDIS design.

3.1.2.2.11 Program Load Module (PLM)

The Program Load Module (PLM) consists of the executable ASDIS program as built by the host system linkage editor or loader. The PLM shall be retained in on-line direct access storage to allow immediate access for execution.

3.1.2.2.12 Data Base Archive (DBA)

The Data Base Archive (DBA) contains the alphanumeric seismic event information and the digital wave-form archive data required by the ASDIS. Storage for the DBA shall be upon direct access disc. The ASDIS shall incorporate the interfaces which permit access to all anticipated seismic data archives. The data base requirements are defined in Section 3.5 and subparagraphs therein.

3.2 DETAILED FUNCTIONAL REQUIREMENTS

The ASDIS program will perform a relatively large number of automatic seismogram measurement tasks. It will then compare the numerical results of the measurements against patterns in the feature vectors for each station inferred from the prior analysis of an historical archive. The emphasis of the program is to perform automatic, not interactive, signal processing, and, therefore, the operator plays a subsidiary role. This is not to suggest that human discretion is irrelevant for seismic discrimination, for ASDIS presupposes careful quality control and preliminary scanning of seismograms before events are passed to it. Furthermore, it is important that seismic analysts carefully scrutinize the results of the ASDIS process, for all ASDIS can do is to assign a number to each observatory's seismograms which quantifies the similarity between the event in question and the earthquake or the explosion seismograms contained in the historical data base. The most challenging problems in seismic discrimination will, of course, be those events for which there are only imperfect templates contained in the historical data base.

It would, in fact, be useful if there were a preprocessing, or postprocessing function (possibly implemented within a data base management program) which presented an English language report as to the similarity of each event to those contained in the historical archive. This report might contain such information as historical events closest in magnitude, historical events closest in location, and call attention to events whose propagation paths traverse anomalous tectonic regions. In the RELS environment, this might be contained within the DISE interactive program.

ASDIS does not require access to the digital wave-forms in the historical data base. Its knowledge of the properties of these wave-forms is passed to ASDIS entirely through the set of feature weights which have been obtained by a prior analysis of these data (see paragraph 1.3.5).

Only a few elementary data base processing functions will be required for ASDIS. These primarily consist of accessing the alphanumeric header, the digital wave-forms, the station information files (including instrument response curves), and updating automatically the ASDIS archive file.

Figure 3.2.1 depicts the top level processing flow diagram for ASDIS. As indicated on this diagram, access to the ASDIS station files and the ASDIS event files shall be limited to "READ ONLY" operations. Additions to, updates of, or modifications of these files are operations which will be performed by functions or programs executed external to the ASDIS. The result of the ASDIS processing will be one or more reports produced on the printer/plotter as well as an updated ASDIS archive file. ASDIS,

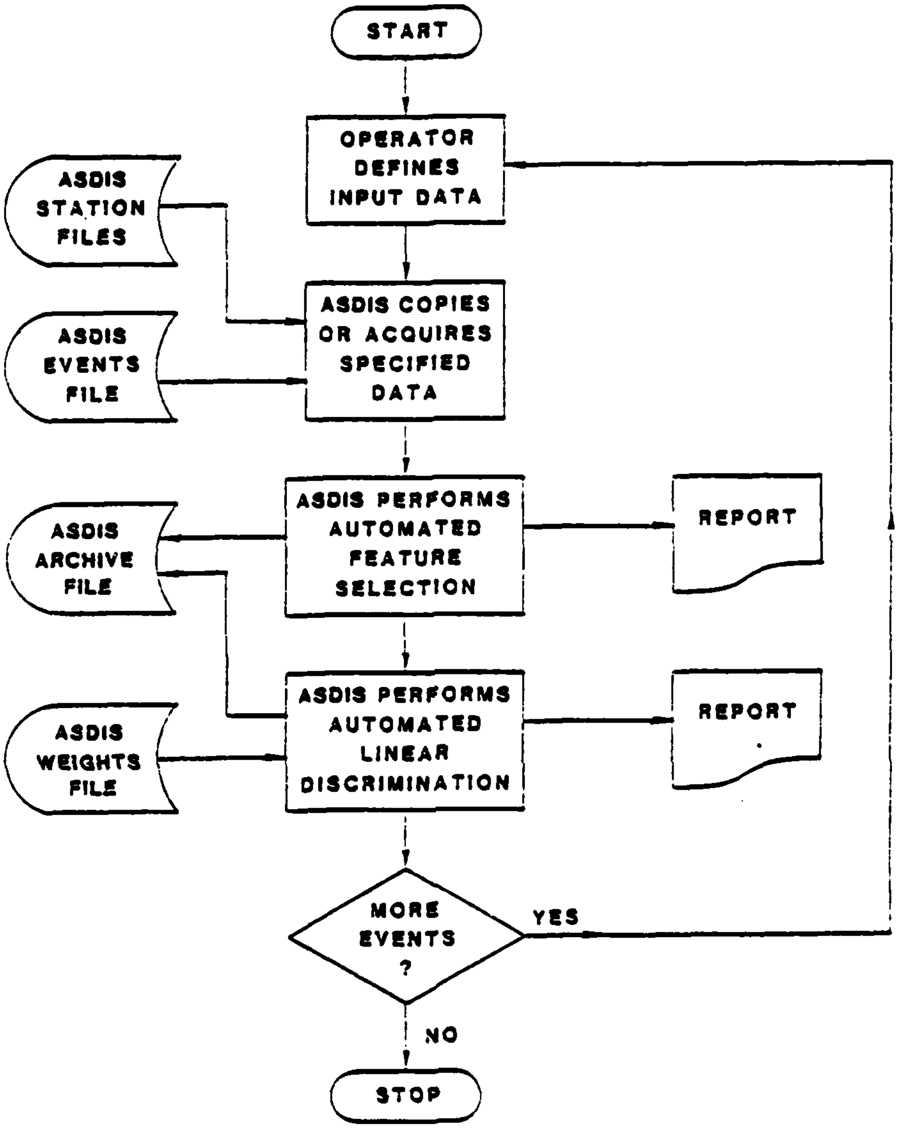


Figure 3.2.1 ASDIS overall functional flow diagram. Feature selection is portrayed more completely in Figure 3.2.2. Linear discrimination is portrayed more completely in Figure 3.2.3. The weights file is generated by a program not part of this system. Station and event files are provided by the ASDIS user. The archive file is the repository for all saved ASDIS output.

itself, has no provision for reading the archive file or using the results contained therein. External to ASDIS there will be required a program to query and analyze the contents of the ASDIS archive file. One clearly defined requirement for the ASDIS archive file processing will be a program to reevaluate the statistical properties of the station and network features vectors, and, thereby, to update the multivariate linear discriminant weights contained within ASDIS.

Figure 3.2.2 depicts the internal functional flow for the automated feature selection block shown in Figure 3.2.1. Figure 3.2.2 indicates that the feature selection tasks can be grouped into the following categories:

(a) Time domain measurements of signal and noise characteristics.

(b) Frequency domain measurements of signal and noise characteristics using Fourier transform spectral methods.

(c) Frequency domain measurements of signal and noise properties using narrowband filtering techniques (MARS).

(d) Ancillary measurements such as complexity, autoregressive moving average (ARMA) wave-form modeling, wave-form spectrum modeling, and event depth.

Definitions of the various symbols and variables which arise in the description of feature selection are provided in Table 3.2.1 along with cross-references to the relevant paragraphs in this report. ASDIS, itself, has no capability for event location or depth determination, and these critical functions must be part of the preprocessing operation. In particular, the only way in which ASDIS uses depth as a discriminant is via the RMS time errors obtained from both a surface focus solution and a free depth solution provided by the location and depth program.

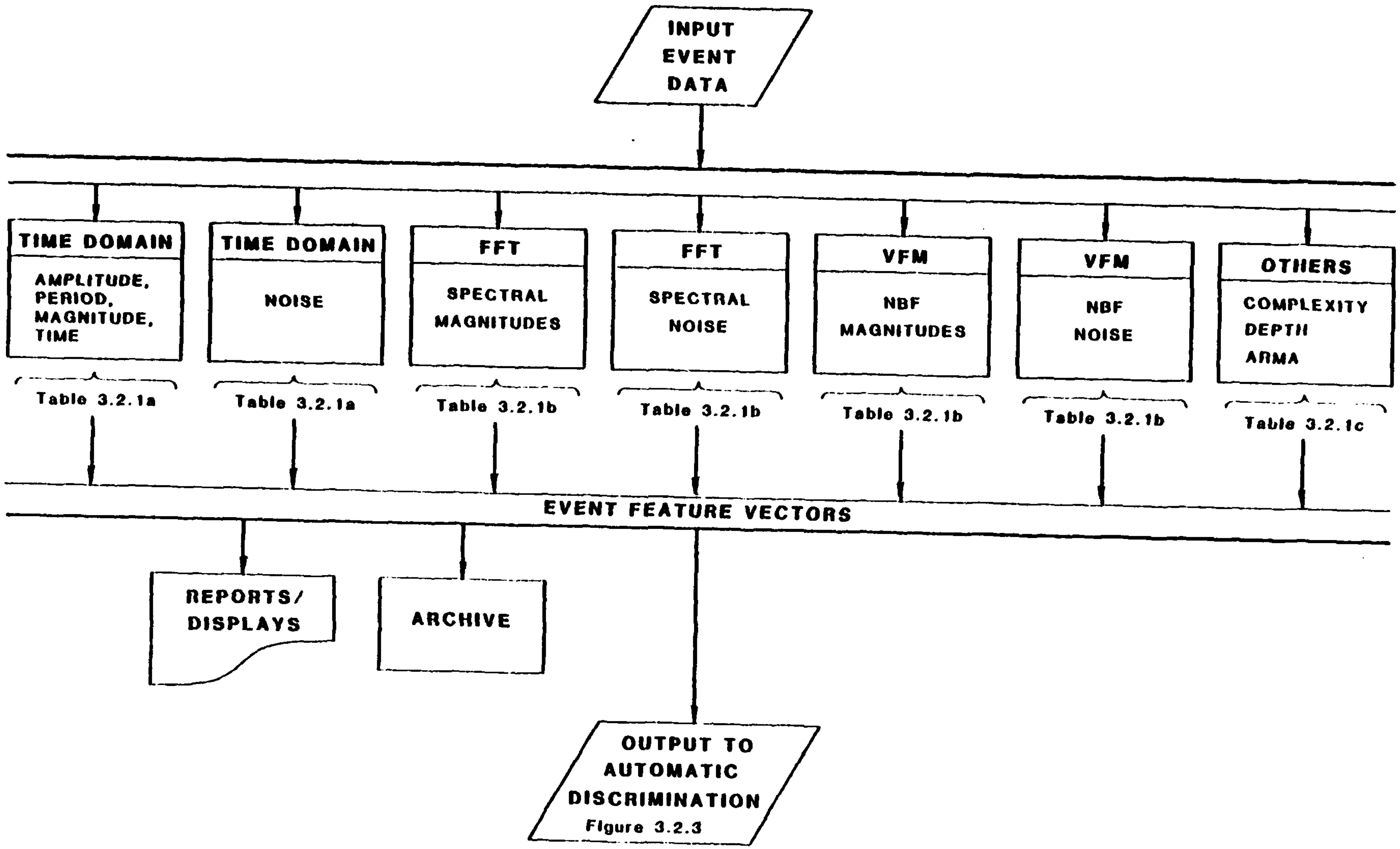


Figure 3.2.2 ASDIS Automated Feature Selection.

Table 3.2.1a Time Domain Features Summary

SYMBOL	DESCRIPTION	REFERENCE
a	Amplitude of first half-cycle of P-phase	3.2.8
a/n_p	Ratio of P-phase first half-cycle amplitude to preceeding background noise	3.2.8
b	Amplitude of second half-cycle of P-phase	3.2.8
b/a	Ratio of P-phase second half-cycle amplitude to first half-cycle amplitude	3.2.8
c	Amplitude of third half-cycle of P-phase	3.2.8
c/b	Ratio of P-phase third half-cycle amplitude to second half-cycle amplitude	3.2.8
LQ	Time domain Love wave amplitude	3.2.9
LR	Time domain Rayleigh wave amplitude	3.2.10
m_b	Time domain body wave magnitude	3.2.11
$\overline{m}_b$	Network body wave magnitude	3.2.13
M_s	Time domain surface wave magnitude	3.2.12
$\overline{M}_s$	Network surface wave magnitude	3.2.13
n_p	Short period RMS noise	3.2.14
n_L	Long period transverse RMS noise	3.2.15
n_R	Long period vertical RMS noise	3.2.16
$t_a, t_b, t_c,$	Arrival times of a,b and c P-wave phases	3.2.8
t_L, t_R	Arrival time of long period Love wave and Rayleigh wave	3.2.9
T_a, T_b, T_c	Period of a, b and c P-wave phases	3.2.9
T_L, T_R	Period of long period Love wave and Rayleigh wave	3.2.10

Table 3.2.1b Frequency Domain Features Summary

SYMBOL	DESCRIPTION	REFERENCE
$m_b(f)$	P-wave FFT magnitude spectrum	3.2.17
$M_L(f)$	Love-wave FFT magnitude spectrum	3.2.18
$M_R(f)$	Rayleigh-wave FFT magnitude spectrum	3.2.19
$n_p(f)$	Short period noise FFT magnitude spectrum	3.2.20
$n_L(f)$	Long period transverse noise FFT magnitude spectrum	3.2.21
$n_R(f)$	Long period vertical noise FFT magnitude spectrum	3.2.22
$tFFT_p$	FFT P-wave window start time	3.2.17
$tFFT_L$	FFT Love-wave window start time	3.2.18
$tFFT_R$	FFT Rayleigh-wave window start time	3.2.19
$VFM_b(f)$	Narrow band filter P-wave magnitude spectrum	3.2.23
$VFM_L(f)$	Narrow band filter Love-wave magnitude spectrum	3.2.24
$VFM_R(f)$	Narrow band filter Rayleigh-wave magnitude spectrum	3.2.25
$VFMn_p(f)$	Narrow band filter short period noise magnitude spectrum	3.2.26
$VFMn_L(f)$	Narrow band filter long period transverse magnitude spectrum	3.2.27
$VFMn_R(f)$	Narrow band filter long period vertical magnitude spectrum	3.2.28
$VFMt_p(f)$	Narrow band filter short period group arrival times	3.2.23

Table 3.2.1b Frequency Domain Features Summary (Cont.)

SYMBOL	DESCRIPTION	REFERENCE
$VFMt_L(f)$	Narrow band filter long period transverse group arrival times	3.2.24
$VFMt_R(f)$	Narrow band filter long period vertical group arrival times	3.2.25

Table 3.2.1c Other Features Summary

SYMBOL	DESCRIPTION	REFERENCE
C1,C2,C3	Complexity feature for three different time windows	3.2.29
P_i	ARMA pole locations	3.2.30
Z_i	ARMA zero locations	3.2.30
σ_s	Standard deviation of arrival times for a source location constrained to be at the surface	3.2.5
σ_f	Standard deviation of arrival times for a free (or unconstrained) source depth	3.2.5
tPa	Arrival time of P-wave from automatic phase picker	3.2.4
tLa	Arrival time of Love-wave from automatic phase picker	3.2.4
tRa	Arrival time of Rayleigh-wave from automatic phase picker	3.2.4
Ω_o	Low frequency level of P-wave spectrum	3.2.30
f_c	Corner frequency of P-wave spectrum	3.2.30
t*	Excess attenuation of P-wave spectrum	3.2.30

Figure 3.2.3 depicts the internal functional flow for the automated linear discrimination block shown in Figure 3.2.1. This is among the simplest of the ASDIS processing functions, for it consists simply of taking linear combinations of seismogram features for each station reporting the event. It must be anticipated that ASDIS will have provision for making new, or unconventional, automatic seismogram measurements, and that, at any stage in its development, ASDIS may measure features for which the historical archive has not been analyzed. Until the discrimination power of a specific feature has been established by analysis of training data, the linear discriminant weights for such features must be given the value zero within ASDIS.

3.2.1 Program Initiation

Program initiation will consist of first performing those operational steps and procedures required for program start-up on the host computer. These procedures and steps will be dependent upon the hardware and software configurations of the host. Since ASDIS will be small enough not to require overlays, program initiation fundamentally will consist of the operator issuing a request to load and execute the program load module (PLM). Once ASDIS program execution has begun, the operator, via the alphanumeric keyboard (ANK) will enter the ASDIS processing parameters. This may be done either through an interactive dialogue with the ASDIS program, or by a request to ASDIS to read an ASDIS parameter file. This latter would be accomplished by issuing the appropriate instruction to the host computer operating system.

3.2.1.1 Inputs

Inputs to the program initiation function consist of the following:

(a) Event name.

(b) ASDIS station file names.

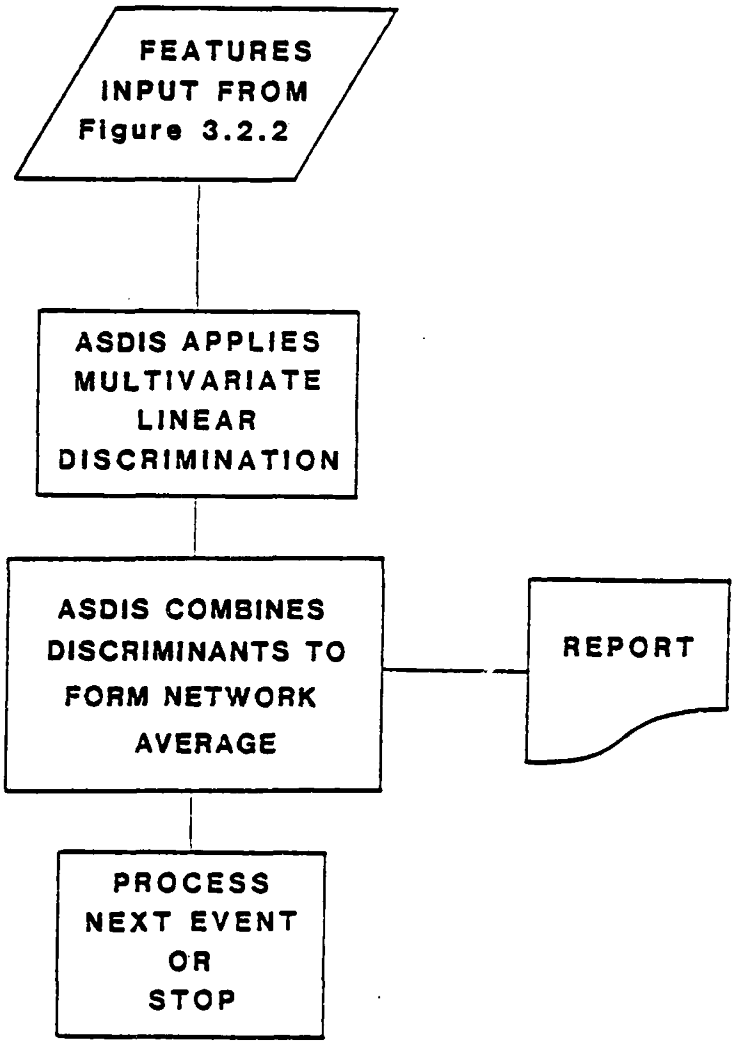


Figure 3.2.3 ASDIS Automated Discrimination accepts event features (both single station and network averages), combines them using linear discrimination and reports final event classification.

(c) Method of phase identification.

(d) ASDIS feature weights file names.

3.2.1.2 Processing

Processing shall consist of those standard program initialization functions required for successful program execution. Among these, for example, are the opening of files for reading and/or writing, and the initialization of variables and parameters.

3.2.1.3 Outputs

Output from the program initiation function shall consist of two hardcopy records produced on the printer/plotter. These shall be:

(a) A complete (or abbreviated) transcription of the event header file.

(b) A program initialization report containing all operator defined processor parameters.

3.2.2 Wave-form Filtering

Filtering of digital seismograms is frequently used to suppress the energy in those parts of the spectrum with poor signal-to-noise ratio relative to the parts of the spectrum where the signal stands out well above background noise. Within ASDIS, wave-form filtering is an optional function which the operator may select prior to executing functions 3.2.4 (phase picking), all of the time-domain signal amplitude measurements (paragraphs 3.2.8 through 3.2.16), or complexity (paragraph 3.2.29). Since ASDIS is an automatic signal processing system, it will not offer the operator a varied library of filter response functions. In fact, it might be desirable simply to offer the option of filter or no filter and use filter parameters contained within the program itself.

3.2.2.1 Inputs

Inputs to the wave-form filtering function consist of:

(a) A digital wave-form.

(b) Filtering parameters consisting of high-corner frequency, low-corner frequency, transition bandwidth, and rejection band attenuation.

(c) The wave-form sample rate and series length extracted from the event header file.

3.2.2.2 Processing

The filter processing shall be accomplished in two stages. The first stage shall be the creation of a set of numeric parameters which specify the impulse response of a phaseless, all zero convolution filter. This shall be done using the algorithms described in Kaiser and Reed (1977, 1978) and Kaiser, (1979). The second step in the processing shall be the convolution of the filter impulse response with the digital seismogram. This shall be done using program FASTFILT described in by Allen (1979). ASDIS will not have the ability to apply different filters to the different seismograms contained within one event, and the main purpose of the filtering is to improve somewhat the signal-to-noise ratio of the body waves from small magnitude seismic events.

3.2.2.3 Outputs

The output of the wave-form filtering function consists of a bandpass filtered replica of all seismograms contained within the event file. The bandpass filtered seismograms will be optionally used by either the phase-picker, the numerous time-domain amplitude functions, or the complexity function. The filtered seismograms will be temporarily saved either in the random access memory, or on high-speed on-line storage and need be retained only for the duration of the execution of the program. Since the filtering parameters will be entered into the processing report log (see paragraph 3.2.1), the filtering function may be easily recreated at a later time if necessary.

3.2.3 System Response Correction

The purpose of the system response correction is to convert signal amplitudes from the digital units used internally by the ASDIS program to natural units, namely earth velocity measured in nanometers per second. Although for interactive seismic discrimination, there is utility in being able to generate filtered time-series which have the response of the instrument partially removed, it is proposed that ASDIS correct for instrument response solely in the frequency domain. In this respect, the system response correction proposed here differs significantly from that described by Sutton and Brady (1980, Paragraph 3.2.48). Thus, the requirement defined here is for a function which returns to the user the amplitude and phase response at one or more frequencies for a specified instrument.

3.2.3.1 Inputs

Inputs to the system response function ccnsist of:

(a) A number or code which denotes the specific instrument under consideration.

(b) The year and date of the recorded event obtained from the event header (this is needed because instrument responses are frequently altered with time).

(c) The set of frequencies at which the instrument response is desired.

3.2.3.2 Processing

Processing consists of locating the desired instrument function in the instrument response tables, interpolating the amplitude and phase to obtain measurements at the desired suite of frequencies.

3.2.3.3 Outputs

Outputs from the system response correction consist of the interpolated amplitude and phase responses of the specified instrument at the desired epoch of time.

3.2.4 Phase-Picker

The ASDIS operator will be able to select one of three possible methods of locating the onset of the seismic wavelet on each digital seismogram. As with the wave-form filtering function, the chosen method will be applied to all seismograms contained within the event file, and the operator himself will not be involved in the visual examination of seismograms. The phase-picking options shall be the following:

(a) Automatic phase identification.

(b) Phase identification by means of previous analyst picks.

(c) Phase identification via origin time and travel-time tables.

For the automatic phase identification, one of the seismic event detection algorithms described by Berger and Sax (1981), Farrell and Wang (1980), and Blandford, et al. (1981) shall be implemented. To communicate the results of a prior analyst study of the events (see option (b) above) body wave or surface wave phase start times shall be entered in several columns of the event header file and thereby made available to ASDIS. For the third option, phase identification through origin time and travel-time tables, ASDIS will read the event origin time from the event header file. It will then use the collection of travel-time tables and ancillary numerical parameters pertaining to the stations in order to calculate theoretical arrival times of the body wave and surface wave at each seismometer position. These tables shall be exhaustive enough so as to include specific time and amplitude anomalies for each station.

3.2.4.1 Inputs

The inputs to the phase-picker function shall be a flag denoting which option is to be exercised for the event under study.

3.2.4.2 Processing

Processing consists of using one of the three techniques described below for specifying the start time of the desired seismic phase on each seismogram.

3.2.4.2.1 Automatic Phase Identification

Automatic identification of events shall be accomplished using the MARS algorithm as described by Farrell, et al. (1980).

3.2.4.2.2 Use of Analyst Phase Times

When analyst phase picks are to be used, the processing shall consist of reading the times from the appropriate locations in the event header file.

3.2.4.2.3 Phase Identification Through Origin Time and Travel-Time Tables

The processing contained here shall consist of a series of table look-up operations which result in a theoretical travel-time from the source location to each seismometer station. This theoretical travel-time will allow for travel-time biases at each station.

3.2.4.3 Outputs

The outputs of the phase-picker will be the arrival times, and phase type of all body wave and surface wave arrivals. For body waves, the onset will be the instant of first motion. For surface waves the onset will be the arrival of energy with a period of 25 seconds. If no energy is detected on any record, then estimated times will be provided, so as to tag the appropriate noise window.

3.2.5 Depth Estimation

Single station depth estimation by means of the automatic recognition of so-called depth phases is so untrustworthy that careful analyst control is mandatory for obtaining satisfactory results. Thus, none of the processing functions keyed to the automatic recognition of depth phases as described by Sutton and Brady (1980) are suitable for inclusion in an automatic system such as ASDIS. With a network of stations available, there is perhaps somewhat more hope that the automatic measurement of depth phases could yield reliable results. For this to be true, however, seismogram measurement functions and epicenter location functions must be tightly knit together. In view of the fact that it remains to be demonstrated whether or not such a complex program could proceed at all reliably without extensive supervision by an analyst. ASDIS, itself, is to have no capability for independently estimating the depth of the seismic event.

Current procedures for determining whether a seismic event is deep enough to be classified as an earthquake involve a number of qualitative evaluations concerning *signal quality* and the depth distribution of previous seismic activity in the epicentral region. While such evaluations are easy enough for a trained analyst to perform, the automation of an algorithm which closely mimics this procedure lies outside the current scope of ASDIS. It is therefore recommended that ASDIS initially contain only an easily automated algorithm for using the depth discriminant and that the option be left available for increasing the sophistication of this ASDIS function later.

The recommended procedure is to implement within ASDIS a pass-fail test based upon a measure of epicenter depth. The test will be made upon two numbers created in the course of locating the event, and passed to ASDIS via the event header file. The two numbers shall consist of the standard deviation of arrival times for a multistation solution obtained by HYPO under the condition in which the focal depth has been constrained to the surface. The second number to be passed to ASDIS shall be the standard deviation of arrival times corresponding to a hypocenter determination in which the depth has been allowed to be free. If we let σ_s and σ_f denote the error in the surface focus solution and the free solution respectively, then the test will consist of:

$$\sigma_s - \sigma_f \geq 2.0 \text{ seconds} \quad .$$

If, simultaneously, $\sigma_s \geq 3.0$ seconds, then the event is classified as deep. It is thereby flagged an earthquake, and it is ignored from further processing. For sources which excite large enough shear waves that they are confidently associated with the event, shear wave arrival time as well as compressional wave arrival times will be used to form the S-P depth discriminant.

3.2.5.1 Inputs

The inputs to the depth estimation function shall be the two RMS time errors defined for the surface focus and free depth epicenter solutions, as well as shear wave arrivals when available.

3.2.5.2 Processing

Processing shall consist of differencing the surface focus and free focus time misfits. The algorithm to define the S-P depth discriminant has not been determined.

3.2.5.3 Outputs

The output shall consist of a message on the alphanumeric terminal and on the printer stating whether or not the event was deep. If the event was deep, then processing shall be terminated.

3.2.6 Fast Fourier Transform (FFT)

For calculating the two types of frequency domain features, it is necessary that the ASDIS be able to perform both the forward and the inverse Fourier transform operation. To accomplish this, the

ASDIS shall incorporate the fast Fourier transform algorithms FFA and FFS described by Bergland and Doland (1979). Program FFA (Radix 8-4-2) is a forward Fourier transform which calculates a complex spectrum from a real input sequence whose length is an integral power of two. The algorithm is similar to the original Cooley-Tukey algorithm but eliminates those operations which are redundant for real series, thus effecting a two-to-one reduction in the calculations and storage requirements. The program FFS (Radix 8-4-2) evaluates a real time series by the inverse transform of a complex frequency series.

3.2.6.1 Inputs

Inputs to the fast Fourier transform function consist of:

(a) A digital wave-form acquired from the event wave-form file.

(b) The digital wave-form length extracted from the event header file, and sample rate.

(c) The start time and end time over which the transform is to be calculated.

(d) Specification of the time-domain tapering function w. The choices, initially, will be between

   (1) Five percent cosine taper.

   (2) Twenty percent cosine taper.

   (3) Gaussian taper.

   (4) Parabolic taper.

3.2.6.2 Processing

The forward Fourier transform takes a real time-series x whose length, N, is an integral power of two and a window function, w, and uses these to calculate the complex spectrum X(k) defined by the equation

$$X(k) = \sum_{n=0}^{N-1} w(n)x(n)e^{-j\frac{2\pi}{N}nk} \quad ; \quad k = 0, 1 \ldots N/2 \quad .$$

The inverse Fourier transform takes the complex spectrum, X, of length N and computes the real series x defined by the equation

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) e^{j\frac{2\pi}{N} nk} \quad ; \quad n = 0, 1 \ldots N-1 \quad .$$

The Fourier amplitude spectrum is defined to be the sequence of real numbers S(k) defined by

$$S(k) = \sqrt{X(k)\ X^*(k)} \quad ; \quad k = 0, 1 \ldots N/2$$

where X* denotes the complex conjugate of the spectrum X.

3.2.6.3 Outputs

The outputs from the Fourier transform function consist of the complex spectrum, X, the real time series, x, or the amplitude spectrum S

3.2.7 Narrow band Filtering (NBF)

The narrowband filtering function (MARS) decomposes a single time series, x, into multiple time series x_i where each x_i is the envelope function of a time series obtained by passing x through a narrowband filter centered at frequency f_i. The ASDIS shall incorporate two lists of center frequencies f_i and width parameters Q_i, one for short-period data and one for long-period data.

3.2.7.1 Inputs

Inputs to the narrowband filtering function consist of:

(a) The digital time series acquired from the event wave-form file.

(b) The time-series length acquired from the alphanumeric event header file and sample rate.

3.2.7.2 Processing

Narrowband filtering shall commence with the calculation of the complex spectrum of the digital time-series as described in paragraph 3.2.6. Evaluation of the several narrowband envelope functions shall use the efficient heterodyne technique described by Seneff (1978) and Farrell, et al. (1981) according to the equation

$$x_i(n) = \frac{1}{N} \sum_{k=0}^{M-1} W_i(k)\ X(k)e^{j\frac{2\pi}{M} nk} \quad ; \quad n = 1, 2 \ldots M-1 \quad .$$

The spectral weighting factors W_i are Gaussian functions centered at frequencies f_i with width parameters Q_i. The index M is equal to M/D where D is the decimation integer. D is a power of two.

Each narrowband envelope function x_i shall be converted to true earth velocity (measured in units of nanometers per second) by applying the appropriate system response correction described in paragraph 3.2.3. The corrected envelope functions, x_i shall next be scanned for maxima as described by Savino, et al. (1979). The values of the K largest envelope maxima $A_i(k)$ and the times of these maxima $t_i(k)$ shall be stored in arrays.

3.2.7.3 Outputs

The outputs of the narrowband filtering functions shall be the narrowband envelope extrema $A_i(k)$ and group arrival times $t_i(k)$.

3.2.8 Time Domain Amplitude and First Motion, P-Wave

For short-period wave-forms, the characteristics of three half-cycles occurring within the first five seconds of the P-wave onset shall be measured automatically. Denoting these excursions a,b and c, a will be the amplitude of the first positive half-cycle, b the amplitude of the immediately succeeding negative half-cycle. The c amplitude will be the largest half-cycle in the remainder of the window. Furthermore, the times of the extrema t_a, t_b and t_c as well as the periods T_a, T_b and T_c shall be measured.

The amplitudes a, b and c shall have positive values for upwards ground motion and negative values for downward ground motion.

3.2.8.1 Inputs

Inputs to the short-period time-domain amplitude function consist of:

(a) A digital wave-form acquired from the event wave-form file.

(b) The P-phase start time acquired from the phase-picker function (see paragraph 3.2.4).

3.2.8.2 Processing

Processing shall consist of:

(a) Wave-form filtering (see paragraph 3.2.2) with a pass band of 0.5 to 2.5 Hz.

(b) Identification of the a, b, and c features as defined above.

(c) The measurement of the amplitudes, periods and arrival times of the three identified features.

(d) The correction of the three amplitudes for the system response as described in paragraph 3.2.3.

(e) If the phase-picker is unable to identify an arrival, or if any of the a, b, c amplitudes are unmeasurable, a noise estimate will be made and so identified.

3.2.8.3 Outputs

The outputs of this function shall consist of the corrected amplitudes a, b and c, the periods T_a, T_b and T_c, and the arrival times t_a, t_b and t_c.

3.2.9 Time Domain Love Wave Amplitude, LQ

The time-domain Love wave amplitude (LQ) is defined to be one-half the maximum peak to peak ground velocity over a single cycle of the transverse long-period ground motion within a designated group velocity window.

3.2.9.1 Inputs

Inputs to the Love wave amplitude function consist of:

(a) The digital wave-forms for two orthogonal, horizontal components of earth motion acquired from the event wave-form file.

(b) The azimuth to the source acquired form the event header file.

(c) The Love wave start time acquired from the phase-picker (see paragraph 3.2.4).

3.2.9.2 Processing

Processing for this function shall consist of:

(a) Calculation of the transverse component of motion by combining the two orthogonal horizontal sensor outputs.

(b) Band pass filtering the transverse seismogram over the period range from 15 to 25 seconds using the wave-form filtering function defined in paragraph 3.2.2.

(c) Scanning the filtered transverse seismogram starting at the Love wave arrival time and continuing to a group velocity of 2.5 kilometers per second for successive extrema.

(d) The amplitude LQ shall be half the difference between the largest adjacent extrema corrected for the instrument response as described in paragraph 3.2.3. For this correction, the period T_L shall be twice the time difference between the selected extrema.

(e) The time t_L shall be calculated from the zero crossing lying between the two identified extrema.

(f) If the phase-picker has not flagged a Love wave arrival, a noise measurement shall be made and so flagged.

3.2.9.3 Outputs

The outputs from this function shall consist of the earth velocity amplitude LQ, period T_L and arrival time t_L.

3.2.10 Time Domain Rayleigh Wave Amplitude, LR

The time-domain Rayleigh wave amplitude (LR) is defined to be one-half the maximum peak to peak ground velocity over a single cycle of the vertical long-period ground motion within a designated group velocity window.

3.2.10.1 Inputs

Inputs to the Rayleigh wave amplitude function consist of:

(a) The digital wave-form for the long-period vertical component of earth motion acquired from the event wave-form file.

(b) The Rayleigh wave start time acquired from the phase-picker (see paragraph 3.2.4)

3.2.10.2 Processing

Processing for this function shall consist of:

(a) Band pass filtering the vertical seismogram over the period range from 15 to 25 seconds using the wave-form filtering function defined in paragraph 3.2.2.

(b) Scanning the filtered seismogram starting at the Rayleigh wave arrival time and continuing to a group velocity of 2.5 kilometers per second for successive extrema.

(c) The amplitude LR shall be half the difference between the largest successive extrema corrected for the instrument response as described in paragraph 3.2.3. For this correction, the period T_R shall be twice the time difference between the selected extrema.

(d) The time t_R shall be calculated from the zero crossing lying between the two identified extrema.

(e) If the phase-picker has not flagged a Rayleigh wave arrival, a noise measurement is made, and so flagged.

3.2.10.3 Outputs

The outputs from this function shall consist of the earth velocity amplitude LR, period T_R and arrival time t_R.

3.2.11 Time Domain P-Wave Magnitude, m_b

For each short-period seismogram contained in the event wave-form file, the ASDIS shall compute the short-period body wave magnitude using the results of the time-domain amplitude measurement (paragraph 3.2.8) and the distance correction factors (B-factors or P-factors) defined in paragraph 3.4.3.10.

3.2.11.1 Inputs

The inputs to the short-period magnitude function consist of the amplitudes and periods of the a, b and c phases of the P-wave measured according to the procedures described in paragraph 3.2.8.

3.2.11.2 Processing

If we let A be the maximum of the a, b, c amplitudes, and T be the corresponding period, then the body wave magnitude for the seismogram is defined by

$$m_b = \log_{10} \left(\frac{A}{T}\right) + B(\Delta) + c \quad .$$

$B(\Delta)$ is the distance correction as defined in 3.4.10. C is a source (and receiver) correction defined in 3.4.3.8.

3.2.11.3 Outputs

The output of this function shall be the single number m_b, the short-period body wave magnitude

3.2.12 Time Domain Surface Wave Magnitude, M_S

The surface wave magnitude, M_s shall be calculated from the Rayleigh wave amplitude LR defined in paragraph 3.2.10. Since the LR amplitude already accounts for the system response correction, the magnitude evaluation defined here requires just the logarithmic scaling, a distance correction, and a station correction factor.

3.2.12.1 Inputs

The inputs to this function consist of the Rayleigh wave amplitude LR defined in paragraph 3.2.10, the LR distance amplitude tables defined in paragraph 3.4.3.12, and the master area magnitude corrections defined in paragraph 3.4.3.8. Alternate m_s formulas may be provided in a later version.

3.2.12.2 Processing

Processing for this function consists of the following operation

$$M_s = \log_{10} (LR) + LR(\Delta) + MALR$$

where $LR(\Delta)$ is found from the distance amplitude table defined in 3.4.3.12, and MALR is the master area Rayleigh wave amplitude correction factor defined in paragraph 3.4.3.8. Alternate M_s formulas may be provided in a later version.

3.2.12.3 Outputs

The output of this function consists of the surface wave amplitude M_s for each long-period vertical component seismogram contained in the event file.

3.2.13 Network m_b and M_s

The network magnitudes are appropriate averages of the body wave magnitude m_b and the surface wave magnitude, M_s, taken over all stations reporting an event. These averages are to be calculated using the maximum likelihood method described by Ringdahl (1976).

3.2.13.1 Inputs

The inputs to this function consists of the individual station magnitudes defined in paragraphs 3.2.11 and 3.2.12.

3.2.13.2 Processing

The processing shall consist of the maximum likelihood estimation of network magnitudes following the method of Ringdahl (1976).

3.2.13.3 Outputs

The outputs of the network magnitude function shall consist of the network magnitudes m_b and M_s.

3.2.14 Time Domain Noise Estimate, Short-Period Vertical

The time domain noise measurement is used to quantify the reliability of the time-domain amplitude measures a, b, and c defined in paragraph 3.2.8. The time-domain noise is defined to be the RMS value of the bandpass filtered short-period seismogram taken over a ten second time window immediately preceding the P-phase onset time defined in paragraph 3.2.4.

3.2.14.1 Inputs

The inputs to this function consist of:

(a) The short-period digital wave-form acquired from the event wave-form file.

(b) The P-phase onset time acquired from the phase-picker function, paragraph 3.2.4.

3.2.14.2 Processing

The first step in the processing for the short-period time domain noise shall be the bandpass filtering of the digital seismogram using the same filter response function which was applied prior to the time-domain amplitude measurements described in paragraph 3.2.8. This filtering shall be accomplished using the wave-form filtering function, paragraph 3.2.2. If x_i denotes the filtered short-period wave-form, then the RMS noise shall be calculated according to the equation

$$n_p = \left[\frac{1}{N} \sum_{i=1}^{N} \left(x(i) - \bar{x}\right)^2 \right]^{1/2} .$$

In this equation, the N time series samples cover the ten second time interval immediately preceding the P-phase onset time and x is the mean value of the wave-form over this time interval. The RMS noise shall be converted to true ground motion by applying the system response correction defined in paragraph 3.2.3. For this correction, the period T shall be taken to be the midpoint of the band used for the wave-form filtering operation.

The RMS noise is most meaningful if the input data has roughly a Gaussian probability amplitude density. Although it has been emphasized that for reliable automatic processing, there must be stringent examination of the seismograms beforehand, it is easy to incorporate here a simple test of the reliability of the noise estimate. This shall be accomplished by counting the number of data points within the noise time window which exceed four times the RMS value. If this number is greater than a predefined limit, then the RMS noise shall be set identically equal to zero. The RMS noise shall also be set equal to zero if there is an insufficient length of noise window preceding the P-phase onset time.

3.2.14.3 Outputs

The output of this function shall be the single number giving the RMS noise of the short-period seismogram over the defined window before the P-phase onset time.

3.2.15 Time Domain Noise Estimate, Long-Period Transverse

The RMS noise in the long-period transverse motion, n_L, shall be calculated in a manner exactly analogous to that used for estimating the short-period vertical noise (see paragraph 3.2.14). This time domain noise measure is used to assess the reliability of the time domain Love wave amplitude defined in paragraph 3.2.9. This noise shall be calculated over a 200 second time window immediately preceding the Love wave onset time.

3.2.15.1 Inputs

The input to this function shall consist of the bandpass filtered transverse component seismogram as defined in paragraph 3.2.9.

3.2.15.2 Processing

The RMS transverse noise n_L will be estimated according to the equation given in paragraph 3.2.14.2. Further, the transverse noise shall be corrected for the system response. Finally, the value is set equal to zero if more than a predetermined number of data points exceed a given threshold, or if there is an insufficient length of pre-event seismogram.

3.2.15.3 Outputs

The output of this function shall be the single number n_L, the RMS transverse long-period noise amplitude over a 200 second window preceding the onset of the Love phase.

3.2.16 Time Domain Noise Estimate, Long-Period Vertical

The RMS noise in the long-period vertical motion shall be calculated in a manner exactly analogous to that used for estimating the short-period vertical noise (see paragraph 3.2.14). This time domain noise measure is used to assess the reliability of the time domain Rayleigh wave amplitude defined in paragraph 3.2.9. This noise shall be calculated over a 200 second time window immediately preceding the Rayleigh wave onset time.

3.2.16.1 Inputs

The input to this function shall consist of the bandpass filtered vertical component seismogram as defined in paragraph 3.2.9.

3.2.16.2 Processing

The RMS vertical noise n_R will be estimated according to the equation given in paragraph 3.2.14.2. Further, the vertical noise shall be corrected for the system response. Finally, the value is set equal to zero if more than a predetermined number of data points exceed a given threshold, or if there is an insufficient length of pre-event seismogram.

3.2.16.3 Outputs

The output of this function shall be the single number n_R, the RMS vertical long-period noise amplitude over a 200 second window preceding the onset of the Rayleigh phase.

3.2.17 FFT P-Wave Magnitude, $m_b(f)$

The spectral magnitude $m_b(f)$ shall be calculated in a manner closely analogous to that defined by Rivers, et al. (1979b). The only deviation from their procedure will be the omission of the averaging over the three frequency bands P_1, P_2 and P_3. This averaging is not required by ASDIS as part of the feature selection operation since it is implicitly contained in the linear weighting of features performed by the multivariate statistical analysis function (see paragraph 3.2.32). To compute the spectral body wave magnitude, a 6.4 second section of digital seismogram shall be extracted starting with the P-phase onset time. The Fourier amplitude spectrum of the signal within this window shall be calculated as defined in paragraph 3.2.6. The Fourier amplitude spectrum will be corrected to true earth velocity at each frequency using the system response correction defined in paragraph 3.2.3. Finally, the velocity spectrum shall be converted to a magnitude spectrum using the conversion formula defined in paragraph 3.2.11. Since the calculations defined herein are all performed in the frequency domain, it will not be necessary to carry out any wave-form filtering as was required for the time-domain body wave measurement.

3.2.17.1 Inputs

Input to the P-wave spectral magnitude function consist of:

(a) A digital wave-form acquired from the event wave-form file.

(b) The P-phase start time acquired from the phase-picker function (see paragraph 3.2.4).

3.2.17.2 Processing

Processing shall consist of:

(a) Calculation of the Fourier amplitude spectrum, S(k) as defined in paragraph 3.2.6.

(b) The correction of the Fourier amplitude spectrum at each frequency for the system response as described in paragraph 3.2.3.

(c) The conversion of the velocity amplitude spectrum to a magnitude spectrum using the equation defined in paragraph 3.2.11.

3.2.17.3 Outputs

The output of this function shall be all spectral magnitudes covering the entire Nyquist frequency range.

3.2.18 FFT Love Wave Magnitude, $M_L(f)$

The spectral Love wave magnitude $M_L(f)$ shall be calculated in a manner analogous to that described by Rivers, et al. (1979b) for their several LQ parameters. As with the spectral body wave magnitude, the feature selection part of ASDIS will not perform any smoothing of the spectrum, relegating this function to the subsequent linear discriminant analysis.

3.2.18.1 Inputs

Inputs to the Love wave spectral magnitude function consist of:

(a) The digital wave-forms for two orthogonal, horizontal components of earth motion acquired from the event wave-form file.

(b) The azimuth to the source acquired from the event header file.

(c) The Love wave start time acquired from the phase-picker (see paragraph 3.2.4).

3.2.18.2 Processing

Processing for this function shall consist of:

(a) The calculation of the transverse component of motion by combining the two orthogonal, horizontal sensor outputs.

(b) The selection of a 128 second time window commencing with the onset of the Love wave phase.

(c) The calculation as defined in 3.2.6 of the Fourier amplitude spectrum , S(k), for the windowed Love wave.

(d) The correction of the Fourier amplitude spectrum for system response as defined in paragraph 3.2.3.

(e) The conversion of the corrected Love wave amplitude spectrum to a magnitude spectrum using the logarithmic transformation defined in paragraph 3.2.12.

(f) The calculation of the ellipticity and polarization in each frequency band, as described by Smart (1977), or using an equivalent algorithm.

3.2.18.3 Outputs

The output of the Love wave spectral magnitude function shall consist of the eight spectral magnitudes covering the approximate period band between 14 seconds and 50 seconds.

3.2.19 FFT Rayleigh Wave Magnitude, $M_R(f)$

The spectral Rayleigh wave magnitude $M_R(f)$ shall be calculated in a manner analogous to that described by Rivers, et al. (1979b) for their parameters LR. As with the spectral body wave magnitude, the feature selection part of ASDIS will not perform any smoothing of the spectrum, relegating this function to the subsequent linear discriminant analysis.

3.2.19.1 Inputs

Inputs to the Rayleigh wave spectral magnitude function consist of:

(a) Digital wave-forms for the long-period vertical component of earth motion acquired from the event wave-form file.

(b) The Rayleigh wave start time acquired from the phase-picker (see paragraph 3.2.4).

3.2.19.2 Processing

Processing for this function shall consist of:

(a) The selection of a 128 second time window commencing with the onset of the Rayleigh wave phase.

(c) The calculation , as defined in 3.2.6, of the Fourier amplitude spectrum , S(k), for the windowed Love wave.

(d) The correction of the Fourier amplitude spectrum for system response as defined in paragraph 3.2.3.

(e) The conversion of the corrected Rayleigh wave amplitude spectrum to a magnitude spectrum using the logarithmic transformation defined in paragraph 3.2.12.

(f) The calculation of the ellipticity and polarization in each frequency band, as described by Smart (1977), or using an equivalent algorithm.

3.2.19.3 Outputs

The output of the Rayleigh wave spectral magnitude function shall consist of the eight spectral magnitudes covering the approximate period band between 14 seconds and 50 seconds.

3.2.20 FFT P-Wave Noise Estimate, $n_p(f)$

As with the time domain P-wave amplitude measures, it is important that there be available a measure of the noise spectrum in order to assign confidence limits to the P-wave spectral magnitudes. In order to accomplish this, all the functions defined in paragraph 3.2.17 shall be repeated on the short-period digital wave-form except that the analysis window shall span a short-time interval immediately preceding the onset of the P-phase. The following arguments show that this window should be approximately 12.5 seconds long.

For a signal whose Fourier amplitude spectrum is S(f), which is masked by random noise of power spectrum density P(f), the proper measure of the signal-to-noise ratio (Farrell, et al., 1980, Equation (A2.4)) is the quantity

$$SNR = \left[\int \frac{S^2(f)}{P(f)} \, df \right]^{1/2} .$$

Since S is a deterministic function, the only uncertainty associated with SNR is that attributable to the uncertainty in the estimation of the power spectrum density function P. By using more and more smoothing in the procedures whereby P is estimated, the variance in P decreases; hence the confidence limits in SNR are reduced. The normalized standard error in P is shown by Bendat and Piersol (1971, equation 6.109) to be

$$\epsilon_p = \sqrt{\frac{1}{B_s T}} .$$

In this equation, B_s is the bandwidth of the seismic signal and T is the time duration of the window over which the power spectrum is estimated. If we wish to know SNR to an accuracy of ten percent, then the standard error in P wants to be one-fifth. Assuming, typically, that the bandwidth of the seismic signal is approximately 2.0 Hz, then this equation leads to the result that T must be 12.5 seconds.

3.2.20.1 Inputs

Input to the P-wave noise estimate function consist of:

(a) A digital wave-form acquired from the event wave-form file.

(b) The P-phase start time acquired from the phase-picker function (see paragraph 3.2.4).

3.2.20.2 Processing

Processing shall consist of:

(a) Calculation of the Fourier amplitude spectrum, S(k), as defined in paragraph 3.2.6, over a 12.8 second window immediately preceding the P-wave onset time.

(b) The correction of the Fourier amplitude spectrum at each frequency for the system response as described in paragraph 3.2.3.

(c) The conversion of the velocity amplitude spectrum to a magnitude spectrum using the equation defined in paragraph 3.2.11.

3.2.20.3 Outputs

The output of this function shall be the 22 spectral noise magnitudes covering the frequency range between 0.303 and 3.75 Hz.

3.2.21 FFT Love Wave Noise Estimate, $n_L(f)$

To provide a measure of the reliability of the Love wave magnitude spectrum, the Love wave noise spectrum for a suitable window immediately preceding the onset of the Love wave shall be calculated in a manner analogous to that used for calculating the P-wave noise spectrum (see paragraph 3.2.20). Following the arguments presented in that paragraph, and assuming that the principal Love wave energy is confined to the period range between 15 and 25 seconds, giving a bandwidth of 0.026 Hz, then the requisite noise window must be approximately 900 seconds long.

3.2.21.1 Inputs

Inputs to the Love wave spectral magnitude function consist of:

(a) Digital wave-forms for two orthogonal, horizontal components of earth motion acquired from the event wave-form file.

(b) The azimuth to the source acquired from the event header file.

(c) The Love wave start time acquired from the phase-picker (see paragraph 3.2.4).

3.2.21.2 Processing

Processing for this function shall consist of:

(a) Calculation of the transverse component of motion by combining the two orthogonal, horizontal sensor outputs.

(b) The selection of a 900 second time window immediately preceding the onset of the Love wave phase.

(c) The calculation as defined in 3.2.6 of the Fourier amplitude spectrum, S(k), for the data within the noise window.

(d) The correction of the Fourier amplitude spectrum for system response as defined in paragraph 3.2.3.

(e) The conversion of the corrected noise amplitude spectrum to a noise magnitude spectrum using the logarithmic transformation defined in paragraph 3.2.12.

3.2.21.3 Outputs

The output of the Love wave noise estimate function shall consist of the eight spectral magnitudes covering the approximate period band between 14 seconds and 50 seconds.

3.2.22 FFT Rayleigh Wave Noise Estimate, $n_R(f)$

To provide a measure of the reliability of the Rayleigh wave magnitude spectrum, the Rayleigh wave noise spectrum for a suitable window immediately preceding the onset of the Rayleigh wave shall be calculated in a manner analogous to that used for calculating the P-wave noise spectrum (see paragraph 3.2.20). Following the arguments presented in that paragraph, and assuming that the principal Rayleigh wave energy is confined to the period range between 15 and 25 seconds, giving a bandwidth of 0.026 Hz, then the requisite noise window must be approximately 900 seconds long.

3.2.22.1 Inputs

Inputs to the Rayleigh wave spectral magnitude function consist of:

(a) A digital wave-form for the long-period vertical component of earth motion acquired from the event wave-form file.

(b) The Rayleigh wave start time acquired from the phase-picker (see paragraph 3.2.4).

3.2.22.2 Processing

Processing for this function shall consist of:

(a) The selection of a 900 second time window immediately preceding the onset of the Rayleigh wave phase.

(c) The calculation as defined in 3.2.6 of the Fourier amplitude spectrum, S(k), for the data within the noise window.

(d) The correction of the Fourier amplitude spectrum for system response as defined in paragraph 3.2.3.

(e) The conversion of the corrected Love wave amplitude spectrum to a magnitude spectrum using the logarithmic transformation defined in paragraph 3.2.12.

3.2.22.3 Outputs

The output of the Rayleigh wave noise estimate function shall consist of the eight spectral magnitudes covering the approximate period band between 14 seconds and 50 seconds.

3.2.23 NBF P-Wave Magnitude $VFM_b(f)$

A superior technique for making spectral magnitude measurements is provided by the MARS (Multiple Arrival Recognition System) processor. Bache, et al. (1980) studied the reliability of the MARS process for spectral magnitude estimation and found that it performed quite well down to rather low signal-to-noise ratios. That MARS processing leads to reliable discrimination for the earthquake and explosion seismograms contained within the Area of Interest data set was exhaustively documented by Savino, et al. (1979) and by Savino, et al. (1980a, 1980b). The function to be implemented here is exactly that described in the above referenced reports.

The MARS processing has two principal advantages over conventional spectrum methods. The first of these is that the frequency resolution of the spectral estimate can vary across the signal bandwidth. In the conventional FFT method of spectral estimation, the frequency resolution is, of course, 1/T where T is the time duration of the signal. The second principal advantage is that MARS permits more exotic phase isolation procedures to be implemented than can be done with straight-forward FFT processing. This phase isolation procedure, for example, often allows one to correct for holes in the spectrum caused by the interference of multiple seismic phases arriving within the analysis time window.

3.2.23.1 Inputs

The inputs to the NBF P-wave magnitude function consist of the narrowband envelope extrema $A_i(k)$ and group arrival times $t_i(k)$ defined in paragraph 3.2.7. Also, the P-phase onset time defined in 3.2.4 is required.

3.2.23.2 Processing

Processing for this function shall consist of:

(a) A search through the group arrival time lists of each narrowband envelope function for that single time which follows most closely the P-phase onset time.

(b) The envelope amplitude A_i corresponding to the designated group arrival time for each frequency band shall be converted to true ground velocity using the system response function defined in paragraph 3.2.3. For this correction, the set of frequencies shall be taken to be the center frequencies of the narrow pass-band Gaussian filters.

(c) The corrected spectral amplitudes shall be converted to magnitudes using the formula defined in paragraph 3.2.11.

3.2.23.3 Outputs

The outputs shall consist of the magnitude and group arrival time of the P-wave for each of the narrowband filters

3.2.24 NBF Love Wave Magnitude, $VFM_L(f)$

The variable frequency magnitude function defined in paragraph 3.2.23 is correct when the seismic wavelet is undispersed. Although Bache, et al. (1980) suggest several techniques for making analogous measurements on dispersed wave-forms, these have been neither implementec nor tested. The function defined here is simpler than those mentioned by Bache, et al., but should perform satisfactorly for events with moderate-to-large signal-to-noise ratio. The method proposed is exactly the same as that defined in the discussion of the NBF P-wave magnitude estimate (paragraph 3.2.23), namely, the magnitude is calculated from the amplitude of the envelope extremum which most closely follows in time the designated Love wave onset time. Although this will yield satisfactory results for normally dispersed surface waves in which the long-period energy travels more quickly than the short-period energy, it may lead to erroneous results for those paths over which the Love wave propagates as an Airy phase.

A subsequent version of ASDIS should incorporate a more refined capability for automatic identification of dispersed waves. This can take one of two forms. For waves received over previously studied paths, Love wave and Rayleigh wave dispersion curves will by stored in the data base, and used either as matched filters to remove dispersion or as reference data to calculate the arrival time of each frequency band. For new paths, it should be possible to construct an approximate dispersion curve from regionalized tables. Alternatively, automatic methods (low order polynomial function, possibly) might be incorporated to identify patterns in the narrow band filter outputs. An important use of dispersion information is to verify that the wave train being processed does indeed come from the event under investigation.

3.2.24.1 Inputs

The inputs to this function consist of the narrowband envelope extrema $A_i(k)$ and group arrival times $t_i(k)$ calculated for the long-period transverse component of earth motion as well as the Love wave onset time. The transverse component of earth motion shall be calculated by combining the signals from two orthogonal, horizontal sensors as defined in paragraph 3.2.9.

3.2.24.2 Processing

The processing of the group arrival times and envelope amplitudes shall proceed exactly as that described for the P-wave spectral magnitude given in paragraph 3.2.23.

3.2.24.3 Outputs

The outputs shall consist of the magnitude and group arrival time for each of the narrowband filters.

3.2.25 NBF Rayleigh Wave Magnitude, $VFM_R(f)$

All the considerations pertaining to the variable frequency magnitude estimate of Love waves, discussed above in paragraph 3.2.24 apply equally well to measurements of Rayleigh waves. As with the proposed measurement of the Love wave variable frequency magnitude, the initial functional requirement for the ASDIS will not include provision for sophisticated analysis of the surface wave dispersion curve.

3.2.25.1 Inputs

The inputs to this function consist of the narrowband envelope extrema $A_i(k)$ and group arrival times $t_i(k)$ calculated for the long-period vertical component of earth motion as well as the Rayleigh wave onset time.

3.2.25.2 Processing

The processing of the group arrival times and envelope amplitudes shall proceed exactly as that described for the P-wave spectral magnitude given in paragraph 3.2.23.

3.2.25.3 Outputs

The outputs shall consist of the magnitude and group arrival time for each of the narrowband filters.

3.2.26 NBF P-Wave Noise Estimate, VFM $n_p(f)$

To provide confidence limits on the NBF P-wave magnitude, it is necessary to estimate the NBF noise magnitude by processing a section of the short-period time series immediately preceding the P-phase onset time. The justification for a 12 second noise window, given in paragraph 3.2.20 in the discussion of the FFT P-wave noise estimate, holds equally here.

3.2.26.1 Inputs

The inputs to this function consist of:

(a) The envelope amplitude extrema $A_i(k)$ and group arrival time $t_i(k)$ as defined in paragraph 3.2.7.

(b) The P-phase onset time as defined in paragraph 3.2.4.

3.2.26.2 Processing

The processing for this function shall consist of:

(a) The identification of all envelope group arrival times for each frequency band which fall within the 12 second time interval immediately preceding the P-phase onset time.

(b) For each frequency band, the envelope amplitudes A_i corresponding to the identified group arrival times shall be arithmetically averaged and converted to ground motion amplitudes using the system response correction defined in paragraph 3.2.3.

(c) Each averaged envelope amplitude shall be converted to a spectral magnitude using the relation defined in paragraph 3.2.11.

3.2.26.3 Ouputs

The output from this function shall consist of one number for each narrowband filter. This number shall be the mean noise magnitude as defined above.

3.2.27 NBF Love Wave Noise Estimate $VFMn_L(f)$

The transverse noise magnitude $VFMn_L(f)$ shall be estimated for a 900 second time window extracted from the transverse component seismogram immediately preceding the Love wave onset time. The arguments supporting this choice of the noise window are exactly those presented in paragraph 3.2.21.

3.2.27.1 Inputs

The inputs to this function shall be the same as those defined in paragraph 3.2.24.

3.2.27.2 Processing

The processing for this function shall be identical to the processing defined in paragraph 3.2.26 except that the envelope amplitudes $A_i(k)$ and group arrival times shall be calculated for the transverse component seismogram as defined in paragraph 3.2.9.

3.2.27.3 Outputs

The output from this function shall consist of one number for each narrowband filter. This number shall be the mean noise magnitude as defined above.

3.2.28 NBF Rayleigh Wave Noise Estimate, $VFMn_R(f)$

The Rayleigh wave noise shall be estimated in a manner analogous to that described for the Love wave in paragraph 3.2.27.

3.2.28.1 Inputs

The inputs to this function shall be the same as those defined in paragraph 3.2.24.

3.2.28.2 Processing

The processing for this function shall be identical to the processing defined in paragraph 3.2.26 except that the envelope amplitudes $A_i(k)$ and group arrival times shall be calculated for the vertical component seismogram.

3.2.28.3 Outputs

The output from this function shall consist of one number for each narrowband filter. This number shall be the mean noise magnitude as defined above.

3.2.29 Complexity, C

The complexity function is an analysis procedure applied to the filtered short-period P-wave. It is a measure of how strongly the energy of that wave is concentrated towards the front at the expense of the subsequent coda. Following Rivers, et al. (1979b), three complexity measures, denoted C_1, C_2 and C_3, are defined. These three complexities differ only with respect to the duration of the coda interval used in the analysis.

3.2.29.1 Inputs

Inputs to the complexity function consist of:

(a) A digital wave-form acquired from the event wave-form file.

(b) P-phase start time acquired from the phase-picker function (see paragraph 3.2.4).

3.2.29.2 Processing

Processing shall consist of:

(a) Wave-form filtering (see paragraph 3.2.2) with a pass-band of 0.5 to 2.5 Hz. (A subsequent version of ASDIS should have optimum frequency bands for each station/source region pair stored in the data base.)

(b) The measurement of the energy contained in the filtered wave-form over four distinct time windows. Signal energy E_s shall be calculated for a five second time window commencing with the P-phase onset time. Coda energy E_1 shall be measured over a time window commencing five seconds after the P-phase onset time and continuing for ten seconds. Coda energy E_2 shall be calculated over a 15 second time window commencing five seconds after the P-phase onset time. Coda energy E_3 shall be calculated for a 30 second time window commencing five seconds after the P-phase onset time.

(c) Complexity C_1 shall be

$$C_1 = \frac{E_s}{E_1} \quad .$$

Complexities C_2 and C_3 shall be calculated in a like manner, substituting E_2 and E_3 in place of E_1 in the above equation.

3.2.29.3 Outputs

The outputs of this function shall consist of the three complexity measures C_1, C_2 and C_3.

3.2.30 P-Wave Spectrum Shape (Ω_0, f_c, and t*)

The wave-form features defined by this function are the quantities Ω_0, f_c and t* studied by Rivers, et al. (1979b) in the course of the AI discrimination experiment. These quantities characterize respectively, the low frequency spectral magnitude, the corner frequency and the high frequency rate of rolloff of the short-period P-wave signal. Many theoretical studies of seismic and explosion sources suggest that these three quantities are diagnostic of the source mechanism. Because teleseismic P-waves are so band limited (on account of attenuation along the path), it is necessary to make assumptions about the asymptotic shape of the P-wave spectrum at high frequencies in order to obtain reliable results for these parameters. Rivers, et al. calculated these three quantities under two alternate hypotheses about the rate of decay of the high frequency spectrum. These were, respectively, that it decayed as frequency to the minus two or frequency to the minus three power. The ASDIS function defined in this paragraph shall be an exact duplication of the processing algorithm of Rivers, et al.

3.2.30.1 Inputs

The inputs to this function consist of the Fourier amplitude spectrum S(k) defined in paragraph 3.2.6, and evaluated for a 6.4 second interval immediately following the onset of the P-phase.

3.2.30.2 Processing

The processing for this function remains to be determined, but will it be identical to that used by Rivers, et al. (1979b)

3.2.30.3 Outputs

The outputs of this function shall consist of two triplets of numbers, the first being the Ω_0, the f_c and the t* estimated under the f^{-2} hypothesis, and the second triplet being these same three quantities estimated under the f^{-3} hypothesis.

3.2.31 ARMA Wave-form Model, P-Wave

The ARMA modeling of signals, which is a widely used method of analysis in speech and acoustics, has received occasional attention by seismologists (Tjostheim, 1975). Although Tjostheim restricted his attention to the all-pole, or autoregressive model, there seems no a priori reason for eliminating the full ARMA model (a mixture of poles and zeros) from consideration. Although algorithms for the ARMA modeling of wave-forms are widely available (see, for instance, Ulrych and Ooe, 1979), the applicability of specific computational methods to seismogram modeling has not thoroughly been investigated; so the requirements for this function remain to be determined.

3.2.32 Linear Discriminant Analysis

Linear discriminate analysis is perhaps the best studied technique in multivariate statistics. It was the method selected by Rivers, et al. (1979b) for combining in an optimum fashion the many different seismogram features which they measured in the course of Area of Interest experiment. It was also the method selected by Farrell, et al. (1981) in their implementation of a rudimentary automatic seismic discrimination system. In order to use linear discriminant analysis for classifying newly observed seismograms, it is necessary previously to have studied a copious data base or historical archive. The best archive, or set of training data, presently available is that assembled by the VELA Seismological

Center in the course of the Area of Interest experiment. First steps into unified processing of the Area of Interest data tapes were presented by Farrell, et al. (1981), and that work continues. Many of the seismogram features contained within the Area of Interest data tapes are identical to those defined in the preceding paragraphs. Thus, the station dependent weighting vectors required before linear discriminant analysis can be applied to most of the features defined above are, or soon will be, available.

An important extension beyond the usual text book discriptions of linear discriminant analysis has been the application of the jackknife technique to obtain robust estimates of the misclassification probabilities. The use of jackknifing in an analysis of the variable frequency magnitude data of Savino, et al. was presented by Farrell, et al. (1981). One great advantage which jackknifing possesses is that it is a nonparametric method of statistics and, hence, does not depend on any assumptions about the Gaussian character of the multivariate probability density function.

In order to implement linear discriminant analysis with jackknife error probabilities, exhaustive statistical calculations are required. These calculations fall outside the requirements of the automatic event discrimination system, and the results alone are of importance here as defined by the features weights file described in paragraph 3.4.1.3.

A subsequent version of ASDIS should also incorporate one of the cluster analysis algorithms described by Meisel (1972).

3.2.32.1 Inputs

Inputs to the linear discriminant analysis function consist of:

(a) The set of features vectors (one for each seismograph station) defined in Table 3.2.1. These all are calculable using the various processing functions defined previously.

(b) The station dependent features weights vectors defined in paragraph 3.4.1.3.

3.2.32.2 Processing

Processing shall consist of the calculation of the dot product between each feature vector and each feature weight vector. For those newly added features which were not contained in the earlier analysis of the historical data set, the weights shall be set identically equal to zero.

The calculation shall be performed on the feature vector for each separate station as well as a network average feature vector. Signal-to-noise weighting shall be used when forming the discriminant function, and classification probabilities will be assigned to the final event classification.

3.2.32.3 Ouputs

The outputs of this function shall consist of the scalar discriminant and the two misclassification probabilities. The scalar disciminant functions shall be saved in the ASDIS archive file (see Figure 3.2.1). Both the individual discriminant functions, the network discriminant functions, and the two misclassification probabilities for each station and for the network shall be presented in a report.

3.2.33 Event Location

Event location is an important discriminant, which will be evaluated for all events for which a reliable hypocenter is available. This will be done in two parts. In the first part, the location will be checked against a digitized map of the continental boundaries, and it will be noted whether or not the event is placed more than 25 kilometers at sea. The second part will check the event location against regionalized seismicity zones (including known testing sites). If the event falls in a known testing site, or within 10 kilometers of a previous underground explosion, it will be noted. In addition, the seismicity search will report which zone, if any, the event falls within, and the historical seismicity (number of events per year in a given magnitude range) of that zone.

3.2.33.1 Inputs

The input to this function will be the event location.

3.2.33.2 Processing

The processing will consist of a search through the following tables:

(a) Continental boundaries.

(b) Known test sites.

(c) Off-site underground explosions.

(d) Regionalized seismicity rates.

3.2.33.3 Outputs

The output will be a report detailing any tables within which a location match was found.

3.3 SPECIAL REQUIREMENTS

3.3.1 Programming Methods

The ASDIS computer program shall be designed to include program and data structures which enhance readability, controllability, testability, extendability, and reliability.

3.3.1.1 Module Definition

A module performs a complete logical process by execution of a set of instructions which have clearly defined inputs, processing logic, and outputs. A module is the smallest set of executable statements able to be assembled or compiled. A module shall consist of a set of instructions in a form consistent with the appropriate language, operating system, and computer.

3.3.1.2 Hierarchical Program Design

Programs shall be designed in a hierarchical manner and the levels of the hierarchy shall correspond to the levels of control of the tasks performed by the program. Each level of the program shall be complete by itself. The lowest level of processing shall correspond to the module. Provisions for incorporating existing modules into the hierarchy shall be made so as to maximize the reuse of previously developed software.

3.3.1.3 Execution Order Programming

Program components shall be programmed in execution order; that is, components at the higher levels in the hierarchical program organization shall be programmed before components at the lower levels. Specifically, calling routines shall be employed in early checkout. Dummy calling routines are not permitted. When a routine is programmed, it shall be programmed to comply with an interface that has already been programmed. When a routine is programmed, it shall always be possible to check it out with components at higher levels in the hierarchy.

3.3.1.4 Standardized Logic

Logic shall be standardized in such a manner as to employ only closed logic structures in the construction of program components. Closed logic structures are structures that have a single entry point and a single exit point exclusive of initialization. All modules shall be coded as closed logic structures.

3.3.1.5 Module Size

Unless otherwise approved, the maximum size of a set of instructions which may be called shall be 100 lines of instructions excluding comments, specification statements, and data definitions.

3.3.1.6 Commenting Standards

ASDIS software should adhere to the commenting standards defined in the following subparagraphs.

3.3.1.6.1 Banners

A banner shall be a block of comments which appears once at the beginning of each module. A banner shall visually break the project software into modular units of code. Banners shall have an identical format for each module. The banner shall enclose the following information: name, title, and number. The banner shall immediately precede the header.

3.3.1.6.2 Headers

Headers shall consist of a block of consecutive comments arranged to facilitate the understanding and readability of each module. Except as otherwise specified herein, this form of block commenting shall be used in lieu of individual comments being scattered throughout a module. Headers shall occur once at the beginning of each module and shall conform to the standards described herein. The observer shall be able to read the MODULE-HEADER and understand the processing activities of the module without having to read program code. The minimum required MODULE-HEADER comments are described below. These comments shall appear in the form and in the order as illustrated in the following list:

(a) MODULE-NAME - followed by a one-line functional description.

(b) ABSTRACT - the ABSTRACT shall be a set of consecutive comments which describe the module's purpose, use and processing activities. Elaboration on the technical aspects of the algorithms should be avoided where references to external documentation would suffice. The ABSTRACT should paraphrase the activities of the code in English terms. References made to external documentation shall be listed in the REFERENCES comment section.

(c) REFERENCES - NO-1, TITLE, DATE (YY/MM/DD)
NO-2, etc.

(d) INPUTS - variables, tables (local, system), files and other data input sources shall be identified separately as to type, unit of measure, size, limits and ranges of unit of measure, accuracy or precision requirements, and frequency of arrival.

(e) OUTPUTS - variables, tables (local, system), files, and other data output sources shall be identified in the same manner as inputs.

(f) PROGRAMS CALLED - names of other programs called followed by brief abstract of purpose and pre- and post-conditions of each call.

(g) LIMITATIONS - descriptions of any constraints upon the execution of the program. For instance, conditions which alter the logical operation of the program or cause the results of the program's computations to be altered.

(h) MODIFICATIONS - NO-1, MOD DESCRIPTION, DATE (YY/MM/DD)
NO-2, etc.

3.3.1.6.3 Special Comments

Wherever code is particularly subtle or confusing, SPECIAL-COMMENTS shall precede the statement(s) to describe the activities of the subject code. SPECIAL-COMMENTS are provided only to aid the observer in reading program code and are not intended to replace MODULE-HEADER comments.

3.3.1.7 Coding Conventions

Computer programs coded for the system shall employ only the control constructs listed below. These constructs shall be built using logically equivalent language simulations. Instructions in the language used shall follow the graphic representation in Figure 3.3.1.1. These constructs are defined as follows:

(a) SEQUENCE - sequence of two or more operations.

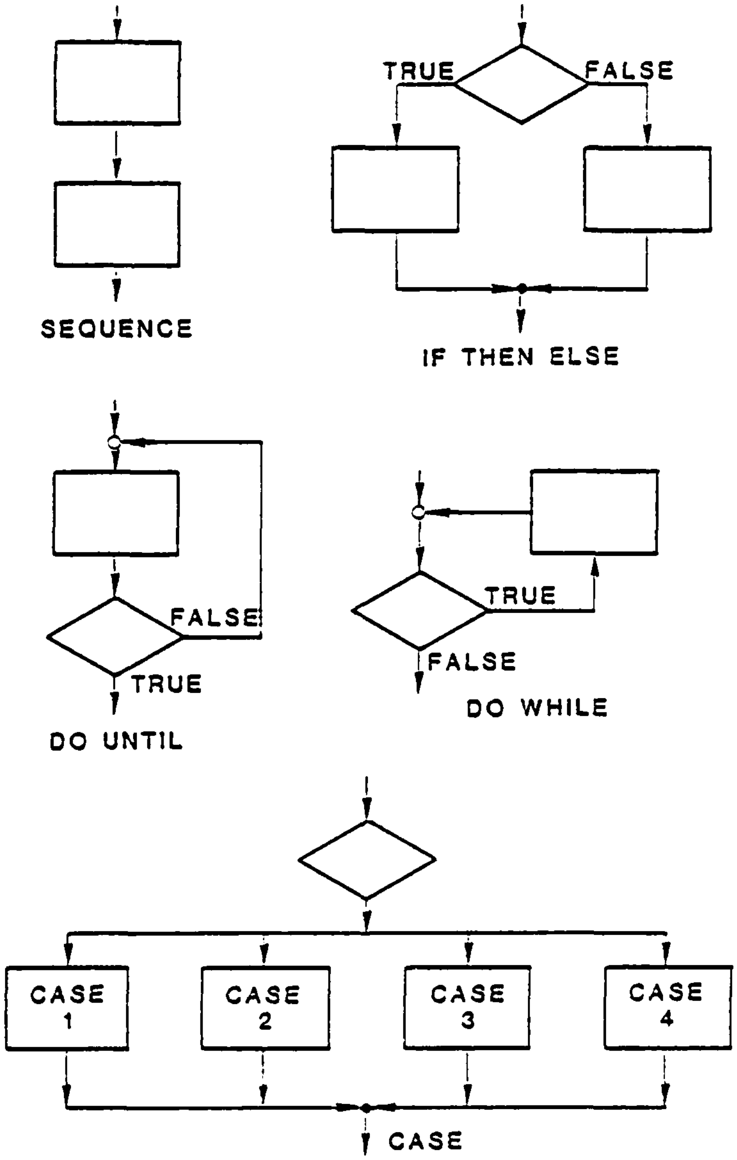


Figure 3.3.1.1 Coding convention examples.

(b) IF-THEN-ELSE - conditional branch to one of two mutually exclusive operations and continue.

(c) DO-WHILE - operation repeated until a condition becomes true. Test is after operation.

(e) CASE - select one of many possible cases.

3.3.1.7.1 Limitations

Coding shall be restricted as follows:

(a) Each line of source code shall contain no more than one statement.

(b) Names of operator commands, data entries, program components, variables, procedures, and other software components shall be consistent with those used in system design.

(c) Code shall be written such that no code is modified during execution.

3.3.1.8 Character Set Standards

Character sets shall conform to standards in FIP-1 Standard Code for Information Interchange, ANSI-X3.4-1977.

3.3.1.9 Programming Languages

All ASDIS programs shall be restricted to the version of the language FORTRAN, defined by ANSI X3.9-1978 and MIL-STD-1753. The compiler features shall be restricted to those implementing the syntax and semantic requirements of the above specified version(s) of the approved standard(s).

3.3.2 Program Organization

The ASDIS program is expected to be small enough to be coded as a single segment which can be contained within the available memory without the use of overlays.

3.3.3 Expandability

The design of the ASDIS shall incorporate provision for future expansion by up to a 10 percent increase in HOL lines.

3.3.4 Error Recovery

The ASDIS program shall incorporate error recovery processes and techniques which will prevent:

(a) Abnormal endings due to invalid operator entries.

(b) Invalid processing results due to other improper parameters.

(c) Host computer abnormal terminations of the ASDIS program for any other cause when such termination could be prevented by utilization of available programming techniques or precedures.

3.4 DATA BASE REQUIREMENTS

The ASDIS will require access to both on-line direct access data files and internal program tables as specified herein.

3.4.1 Sources and Types of Input

The exact structure, content and format of the ASDIS input data is dependent upon the design of the data base management system with which it interfaces. The following subparagraphs define in general terms the input requirements.

3.4.1.1 Event File

Used as a semipermanent working file, the Event File will be used to store wave-form and alphanumeric data. This file contains the principal data required by the ASDIS program. Data stored on this file must be immediately available to the ASDIS program. The minimum capacity for the Event File is estimated at 300 kilobytes when only a few sensors from each station are to be processed. If it happens, however, that stations consisting of arrays are used, and when all array elements are contained in the file, it could easily reach a size in excess of 1 mbyte.

A good arrangement of the Event File would be to structure it in several divisions. The first division could be an alphanumeric header division which contains event information, station codes, short period and long-period start times for the seismogram windows, distance and azimuth information, and phase arrival times for those seismograms which have been picked by an analyst. Figure 3.4.1.1.1 shows how the header division might be organized. The second division could contain the digital seismograms for a single short-period vertical sensor from each of the reporting stations. Each seismogram shall contain 50 seconds of ground motion data, as is indicated in Figure 3.4.1.1.2. The third division could contain three component long-period seismogram information from each station recording the event. This division could be organized in three blocks -- the first block containing all available seismograms for the long-period vertical sensor; the second block, all seismograms for the long-period north-oriented sensor; and the third block, all available seismograms for the long-period east-oriented sensor. Each seismogram within the block should be approximately 2000 seconds long. Fourth and subsequent divisions could contain the individual short-period vertical sensors for those stations at which arrays are located. Each of these divisions could be proceeded by a short alphanumeric header giving the station name and, when available, analyst picks of the phase arrival information. The window start times and other parameters for these divisions could be identical to the parameters contained in the alphanumeric header division of the event file.

3.4.1.2 System Response File

The System Response File (which will be approximately ten kilobytes long) should be defined, which will contain all the calibration curves for both the long-period and short-period sensors at each of the seismic stations. These curves should give, over a

```
Event: 317   Class: Ex  Location: Shagan River
Lat: 49.987   Lon: 78.949   Depth:    0.0      Mb: 6.0
Date: 28 Oct 79    O-time: 303:03:16:56.9      Ms: 4.18

Sta    Sp# Lp#  Ssr Lsr  S.p. start time    L.p. start time    Dist.    Delta  Azim.

ANMO   000 002   20   1
BOCO   005 007   20   1
CHTO   010 012   20   1  302:03:23:38.0    302:03:23:34.1    3892.8    35.0   337.3
CTAO   015 017   20   1
GUMO   020 022   20   1
KAAO   025 027   20   1  302:02:20:42.3    302:03:12:30.1    1897.3    17.2    22.2
MAIO   030 032   20   1
MAJO   035 037   20   1  302:03:24:53.4    302:03:29:09.5    4900.4    44.1   307.1
NUAO   040 042   20   1
SNZO   045 047   20   1
TATO   050 052   20   1  302:03:24:30.2    302:03:27:23.9    4581.8    41.2   318.5
ZOBO   055 057   20   1
ANTO   060 062   20   1  302:03:23:26.6    302:03:22:45.9    3749.3    33.7    57.0
SHIO   065 067   20   1
KONO   070 072   20   1  302:03:24:14.2    302:03:26:13.7    4372.3    39.3    72.4
GRFO   075 077   20   1

Comments:
%
```

Figure 3.4.1.1.1 Event header example.

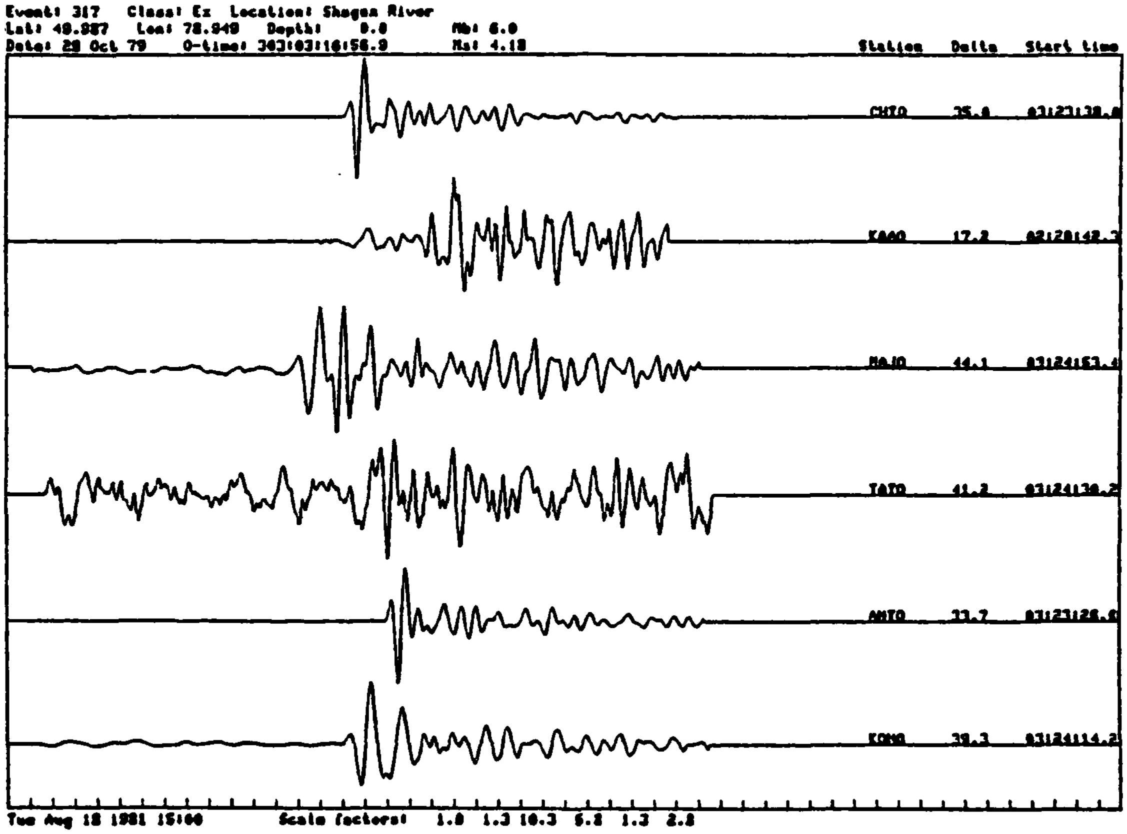


Figure 3.4.1.1.2 Short-period wave-form example.

suitable range of frequencies, both the amplitude response and the phase response of each of the sensors. These responses should be normalized so that the amplitude response is unity at a one second period for short-period instruments, and so that it is unity at a 25 second period for the long-period instruments.

3.4.1.3 Feature Weights File

The Feature Weights File (which will be approximately ten kilobytes long) will contain all the weighting factors which are required in the linear discriminant analysis of seismogram feature measurements. These weighting factors, as described by Farrell, _et al._ (1981), are evaluated from the statistical analysis of historical data.

This file should contain, in addition to the feature weights, the means and variances of each feature for both populations, as well as the means and variances of the discriminant function. There should be a network average record, as well as records for each separate station. A subsequent version of ASDIS may further subdivide the feature records into source regions. This file will be approximately ten kilobytes long.

3.4.2 Destination and Types of Outputs

Outputs from the ASDIS will consist of alphanumeric data containing the intermediate and final results of discrimination, and reports consisting solely of alphanumeric data. The following ASDIS outputs are defined:

3.4.2.1 Event Feature File

This file, which comprises part of the ASDIS archive file (see Figure 3.2.1) contains the numeric values obtained for each seismogram in the Event File by applying the suite of automatic measurement algorithms described in Section 3.2. Each of these feature values for every individual seismogram will be accompanied by an alphanumeric discriptor which is the key to the measurement procedure used. In addition, each measured feature shall have a time associated with it so that the epoch of measurement can easily be identified on the original seismogram.

3.4.2.2 Event Discriminant File

This file which comprises the other part of the ASDIS archive file will be used for the permanent storage of the results obtained from the linear discriminant analysis of the event features described in the preceding paragraph.

3.4.2.3 Printer/Plotter Reports

Two types of reports will be generated by the ASDIS program. The first report shall be a verbatim copy of the operator entered processing parameters which are fixed during program initiation (see Section 3.2.1). The second sort of report will be the final discrimination analysis report which shows, for each reporting station, the station code, the results of the discrimination analysis, the probabilities that the event was an earthquake or an explosion, and the summary conclusion from the network as a whole. An example of the printer/plotter discrimination report was shown in Figure 3.2.32.1.

3.4.3 Internal Tables and Parameters

The ASDIS will require access to the tables listed in the subparagraphs following. A summary of the required tables is given in Table 3.4.3.1 which gives discriptions, internal references, and the ASDIS requirements paragraph in which each individual table is needed. Three general types of tables are identified. The first type are tables which provide discriptions of the seismometer network. The second set of tables are tables which describe the amplitude and travel-time characteristics for waves emanating from specific source regions to each of the seismometers in the network. The third set of tables are tables which are used to derive correction factors which are applied to raw signal measurements to yield features upon which discrimination is applied.

Table 3.4.3.1 Internal Tables

TABLE	DESCRIPTION	REFERENCES (INTERNAL/EXTERNAL)
Station Location/ Array Displacement	Geographic Position of seismic sensors	3.4.3.1/None
Station Code Alias	Symbolic names for seismic sensors	3.4.3.2/None
Herrin 1968 Travel Times	Average P-wave travel times, spherically symmetric earth model	3.4.3.3/Herrin, 1968
Ellipticity Correction	Correction to P-wave travel time due to equatorial bulge	3.4.3.4/Bullen, 1976
Source Region/ Station Time Correction	P-wave time delays due to crust and mantle structure	3.4.3.5/None
Regionalized Surface Wave Group Velocities	Love wave and Rayleigh wave travel time table	3.4.3.6/None
Master Area Arrival Time Correction	Unknown	3.4.3.7/None
Master Area Magnitude Correction	P-wave magnitude anomalies	3.4.3.8/None
Period Correction Factors	Unknown	3.4.3.9/None
B Factors	Average P-wave amplitude as a function of distance	3.4.3.10/Veith and Clawson, 1972
Geometrical Spreading	Distance correction for long period spectral level	3.4.3.11/Rivers et al. (1979b)
LR/LQ Amplitudes	Distance correction for surface waves	3.4.3.12/Rivers et al. (1979b)
Complexity Factor Correction	Station dependent complexity correction	3.4.3.13/None
VFM Narrowband Filters	Center frequencies and widths of filter comb	3.4.3.14/Savino et al. (1980a)

3.4.3.1 Station Location/Array Displacement Table

The Station Location Table shall contain station codes, station locations, and the station elevations for all stations in the network. The station location coordinates are stored in values of geocentric colatitude and east longitude. In addition, for those stations at which arrays are located, there shall be the displacement of each array element from the center of the array as well as the loction of the array center with respect to the fiducial location of the station. The displacement shall be stored as x, y value pairs in kilometers with positive values representing North and East, and negative values representing South and West.

3.4.3.2 Station Code Alias Table

There frequently are several alternate ways by which a seismometer station, or seismometer component can be designated. For example, SRO stations are often referenced by the four letter alphabetic codes, but in addition, there is a set of numeric codes which are in frequent use at the Seismic Data Analysis Center. The tables specified in this paragraph shall provide all possible cross references so that, no matter which method of designation is used, all other aliases will be returned.

3.4.3.3 Herrin (1968) Travel-Time Table

The ASDIS shall contain the P-wave travel-time table as contained in the report by Herrin (1968) for focal depth ranging from zero kilometers to 125 kilometers. This table shall contain floating point values of an accuracy of at least three decimal places. This table is only required if Option C of the phase-pick algorithm (paragraph 3.2.4.2.3) is implemented.

3.4.3.4 Ellipticity Corrections

Since the Herrin tables assume wave propagation through a spherically layered earth, a small correction is required to the travel-time to account for the equitorial bulge. A table shall be provided which implements the ellipticity correction that is described by Bullen (1976, Equation (30), p. 175). This table shall contain floating point values with an accuracy of two decimal places. This table is only needed if Option C of the phase-pick algorithm is implemented.

3.4.3.5 Source Region/Station Time Corrections

To account for the few second delays in travel-time through the crust and upper mantle beneath the source regions and beneath the individual seismometer stations, there should be a source region/station time correction table. This table shall contain floating values with a required accuracy of at least five decimal places. This table also is required only if Option C of the phase-pick algorithm is implemented.

3.4.3.6 Regionalized Surface Wave Group Velocity Tables

The time it takes a surface wave to travel from an epicenter to a seismometer station is much more variable than is the time required for a P-wave to connect to the same two points. If Option C in the phase-pick algorithm is implemented, then it will be required to have available a regionalized surface wave/group velocity table so that, for any specified path, the total propagation time for surface waves of several different periods may be accurately calculated. A table such as this exists currently at the Seismic Data Analysis Center.

3.4.3.7 Master Area Arrival Time Corrections

Master area arrival time correction are specified in the discrimination report by Sutton and Brady (1980, paragraph 3.5.3.5). These possibly will need to be incorporated into ASDIS as well if Option C of the phase-pick algorithm is implemented.

3.4.3.8 Master Area Magnitude Corrections

These, too, are specified by Sutton and Brady (1980, paragraph

3.5.3.11), and the tables may need to be incorporated into ASDIS as well. They are probably only needed for the time-domain amplitude algorithms specified in Section 3.2.

3.4.3.9 Period Correction Factors

Tables of short-period and long-period period correction factors are referenced by Sutton and Brady (1980, paragraph 3.5.3.10). They are probably allied with the methods for picking short-period and long-period amplitudes in the time-domain .

3.4.3.10 *B- or P-Factors*

Tables of B-factors (Gutenberg and Richter, 1956) or P factors (Vieth and Clawson, 1972) are needed to convert logarithmic amplitude measurements to magnitudes. Sutton and Brady (1980, Table 3.5.3.1, page 147) refer to these as distance-depth correction factors, but this is almost certainly in error.

3.4.3.11 Geometrical Spreading Tables

This is a table of unknown utility which was first defined by Rivers, et al. (1979b), and plots of these tables appear in Rivers, et al. (1979c). In the subsequent report, in fact, these tables were not used in the analysis of their data. The purpose behind these tables is to correct the long-period spectral level, $_0$, for distance. $_0$ itself is obtained by fitting a simple transfer function to the short-period P-wave spectrum (see paragraph 3.2.30). It appears from Rivers, et al. (1979c) that this table was not used in their final analysis, and the correction of spectral level for distance is simply obtained by taking the P- or B-factor tables defined in paragraph 3.4.3.10 above.

3.4.3.12 LR/LQ Distance Amplitude Tables

These tables are the long-period analog of the B- or P-factor tables defined in paragraph 3.4.3.10 and are used to change either time domain or frequency domain measurements of long-period surface wave amplitudes into magnitudes. These tables are defined in Rivers, et al. (1979c) Equation (1) page 34. The key parameter in this table is the attenuation constant, γ. In general, γ depends on frequency and propagation path. As studies of surface wave propagation effects continue, we may expect that this table will become more and more complex as more and more paths are studied individually.

3.4.3.13 Complexity Factor Corrections

We are not yet clear about the purpose of the complexity factor corrections which appear in Sutton, et al. (1980, paragraph 3.5.3.14). Their reference for the complexity factor correction table is the wave-form processing system (WPS) program written by GEOTECH.

3.4.3.14 VFM Narrow Band Filter Table

This table defines, for each seismograph station, the center frequencies and the Q's of the comb of narrowband filters used for the variable frequency magnitude method of discrimination. Initially, all stations will be assigned the same comb of filters, but it must be possible to expand this table to account for station independent filter selections. The reference for the VFM Filter Tables is Savino, et al. (1980a).